BROWN BOVERI REVIEW

380-kV Chute-des-Passes Power Development of the Aluminum Company of Canada

For this important Canadian e.h.v. system Brown Boveri supplied an extensive power line carrier installation, all airblast circuit-breakers and current transformers, as well as all the line protection gear. The picture shows part of Isle Maligne substation with a 380-kV coupling capacitor and suspended 2000-A wave trap (on the right) and a 380-kV circuit-breaker (left).

(Courtesy Aluminum Company of Canada)

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CONTENTS:

THE INDOOR AIRBLAST CIRCUIT-BREAKER, ITS DEVELOPMENT TO HIGHER RATINGS

621.316.57.064.45

The design of an improved model of the indoor airblast circuit-breaker, whose performance data have been considerably increased, allowing it to be used for the protection of large transformers and for connection to busbar systems, is described in the present article, which also discusses further possible variants of the design and the applications visualized.

A QUESTION which attracts considerable attention when high-voltage networks of high capacity are being planned is the problem of the circuit-breakers available for the visualized installations. The increasing type ratings of generators and transformers are characteristic of the evolution which has taken place during the last ten years. Likewise the busbar ratings of power stations have risen to very high figures. As a result, breakers are now being specified for extraordinarily high rated data, while at the same time additional requirements are imposed regarding the fulfilment of their duties in normal service, as well as under various short-circuit conditions.

Previous articles have described how it is possible to produce various models of airblast circuit-breakers for indoor installations, using the Brown Boveri unit construction principle, and how these units can master extremely severe duties [1]. A task of this kind was imposed by the Swedish State Power Board when they were planning a new hydro-electric power plant. The generators and transformers are connected to the 18-kV station busbars by airblast circuit-breakers. Among the switchgear supplied by the Company are also the breakers used to connect the low-voltage windings of a 600-MVA transformer bank, comprising three single-phase units with a reserve unit, to two sets of busbars. Now that these breakers have been tested and successfully commissioned, a brief account will be given of the difficulties which had to be overcome.

Installation Planning

When determining what type of circuit-breaker is to be employed and what data it shall possess, it is customary to start from the characteristic data of the electrical side of the installation and the circuit diagram. If high station outputs have to be fed through a transformer bank into a power system

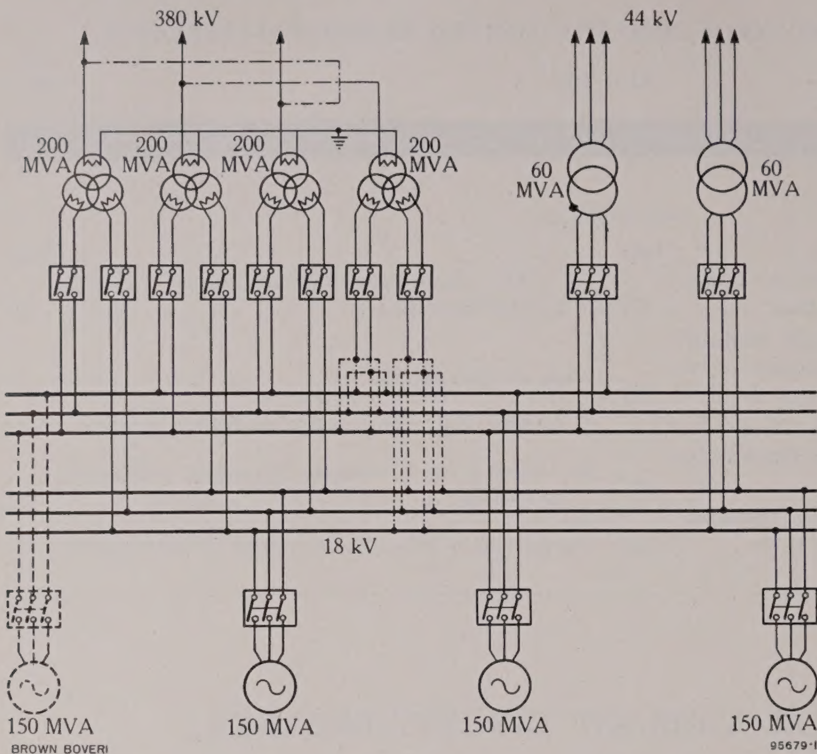
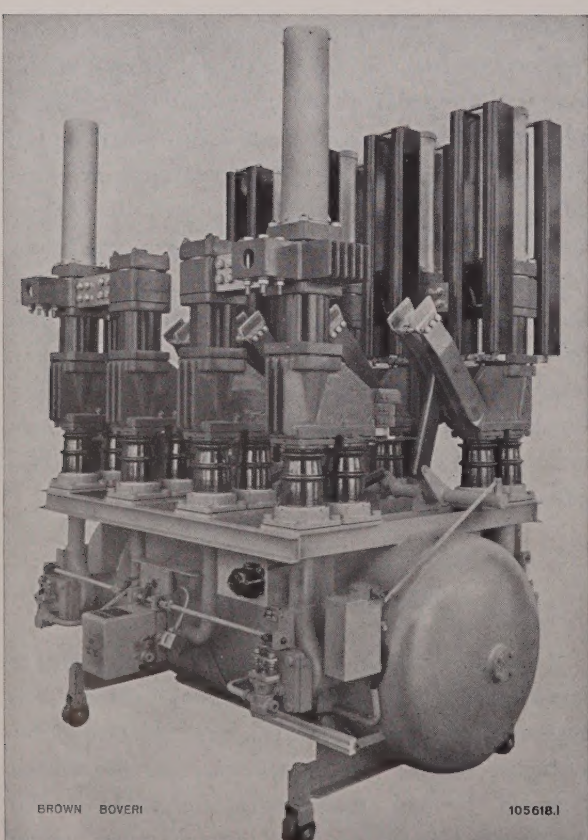


Fig. 1. – Circuit diagram of a Swedish power station for which Brown Boveri have so far supplied 13 high-capacity airblast circuit-breakers for the 18-kV installation



direct, the solution with single-phase units has certain economical and technical advantages. If the maximum service current exceeds certain limits, owing to the type rating and voltage chosen, the low-voltage side of each single-phase transformer unit will contain two or more windings. Each of these windings is then connected to two conductors of an allocated busbar system. By this means it is possible not only to split up the service current definitely, but also to divide up the short-circuit power.

A generating station in northern Sweden is laid out according to the circuit diagram shown in Fig. 1. By means of pairs of double-pole circuit-breakers the l.v. side of the single-phase transformer units are

Fig. 2. – Double-pole airblast circuit-breaker

Rated voltage	18 kV
Rated current	6000 A
Symmetrical breaking current	100 kA
Asymmetrical breaking current	125 kA
Rated short-time current (1 s)	200 kA

connected to the busbar systems. According to the plans visualized for the final size of this station, the characteristic data of the transformers indicate that symmetrical short-circuit currents of up to 100 kA will be feasible. The symmetrical breaking capacity of a set of three double-pole breakers is thus 5400 MVA at a voltage of 18 kV. The electrical data of the double-pole breaker illustrated in Fig. 2 were determined in accordance with the Swedish Standards for high-voltage a.c. circuit-breakers [2].

Design of the Breaker

Fundamentally the design of the breaker does not differ to any great extent from that of the normal type DB indoor airblast circuit-breakers. Its principle feature is the completely new conception of the arrangement of the various points of interruption, which gives the unit its current-carrying capacity and its breaking capacity. Not only the elements which have to carry the current, but also the control and actuating elements are well-tried components of the standard breaker range. The breaker depicted in Fig. 2 has each pole connected to provide two current paths, as may be seen in the circuit diagram in Fig. 3. In the one path there is a power interrupter 1 and a voltage isolator 5a. The other path contains three power interrupters 2, 3, 4 and a voltage isolator 5b. Each of the power interrupters is a modified version of the standard high-breaking-capacity airblast extinction chamber. The voltage isolators are composed, in their moving parts, of normal isolator blades from indoor airblast breakers, and are jointly operated by compressed air on each breaker. In the closed state each current path carries a share of the current in proportion to its admittance.

The actual process of interruption performed by each pole begins with the opening of interrupter 1, parallel to which are the three interrupters in the other path. Ten milliseconds later these three interrupters open simultaneously. At the interrupters 3 and 4 the conditions for interruption are the most favourable possible, because low resistances are connected in parallel with the interrupter. They ensure that the shares of the recovery voltage are equal and that the transient is aperiodic. The

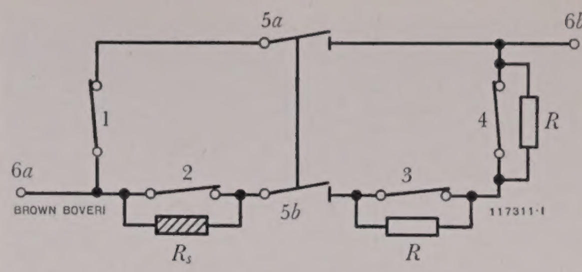


Fig. 3. – Diagram depicting the current paths of one pole of the circuit-breaker in Fig. 2

1–4 = Power interrupters
5a, 5b = Voltage isolators
6a, 6b = Line terminals
R = Parallel resistors of low ohmic value
R_s = Non-linear resistor (voltage-dependent)

residual current flowing through the resistor R is subsequently interrupted by 2 the first time it passes zero. This current only has a very small inductive component so that the recovery voltage remains a power-frequency phenomenon. Thus the breaker is suitable for use under network conditions and for switching duties for which a very rapid rate of rise of the restriking voltage would be calculated for uninfluenced interruption. The non-linear resistor R_s in parallel with interrupter 2 ensures that the overvoltage on interruption can under no circumstance exceed a certain limit in the range of low inductive currents. The voltage isolators 5a and 5b open after a time-lag, but still during the blast time, thereby breaking the residual current determined by the non-linear resistance R_s. This final phase of arc extinction completes the breaking action. The breaker is closed by simultaneously closing the two voltage isolators.

Testing the Breaker

A development programme for circuit-breakers, even when well-tried components are utilized, nevertheless involves exhaustive experiments and tests. The remarks which follow describe some of the type tests performed to prove that the breakers were capable of the performance claimed, which were carried out in the high-power testing station of KEMA[1] the results of which are illustrated here in a

[1] Keuring van Electrotechnische Materialen, Arnhem (Holland).

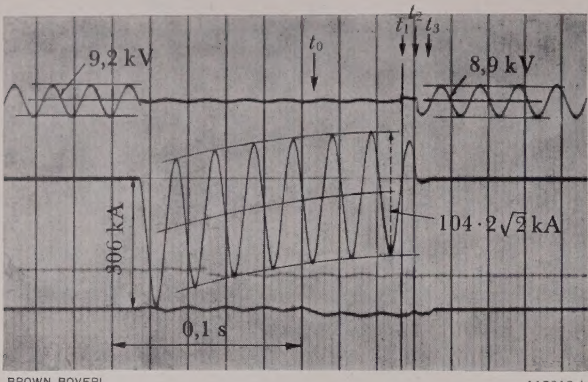


Fig. 4a. – Oscillogram of the last "Make–Break" operation in a test sequence "O–3 min—C–O–3 min—C–O" on a single-pole breaker

Voltage across one pole	9·2 kV
Peak making current	306 kA
Symmetrical breaking current	104 kA
Recovery voltage	8·91 kV

t_0 = Moment at which the "Off" command is given
t_1 = Moment the contacts part
t_2 = First stage of arc extinction
t_3 = Residual current arc finally extinguished

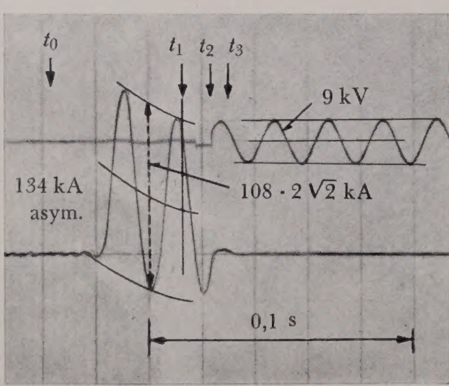


Fig. 4b. – Oscillogram of the test to prove the asymmetrical breaking current of 134 kA, by employing a symmetrical current of 108 kA

Recovery voltage across one pole 9·00 kV
t_0–t_3 as in Fig. 4a

selection of oscillograms, permission to publish which is hereby gratefully acknowledged.

The proof of the breaking capacity was obtained by testing in accordance with the recognized rules of IEC [3], after the unusual conditions imposed by the nature of the switching operation and the network conditions had been discussed with the customer. For instance, one question raised was that of the natural frequency of the test circuit. Since, owing to the manner of operation of the breaker, the breaking capacity is not affected by such conditions of the test circuit, the breaking capacity was established at the natural frequency of the testing station. In actual fact cathode-ray oscillograms were utilized to determine the conditions prevailing in the test circuit, evaluation of which showed a frequency of 18000 c/s, a value only encountered in testing stations. The symmetrical and asymmetrical rated breaking currents were confirmed at a recovery voltage per pole of 9 kV, for which, with phase opposition, it was necessary to switch with a recovery voltage of 18 kV.

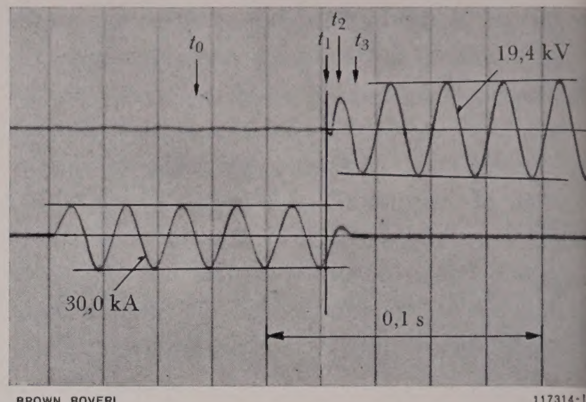


Fig. 4c. – Oscillogram from the test cycle to prove the breaker's ability to interrupt in the event of phase opposition on one pole

Breaking current	30·0 kA
Recovery voltage across one pole	19·4 kV

t_0–t_3 as in Fig. 4a

The closing time measured was 0·111 s and the break time (not including arcing time) was 0·048 s. Having completed the test cycles with 10, 30 and 60% of the rated breaking current, the contacts only exhibited moderate traces of arcing, as were to be expected after nine interruptions. The final operation at 100% making current and breaking current, with three breaking and two making operations, is illustrated by Fig. 4a.

It was proved that, during making, both isolator blades and thus both current paths carry an equal share of the load. It was consequently possible to

admit a making current considerably higher than 1·8 $\sqrt{2}$ times the asymmetrical value of the breaking current rating. The breaker was thus able to achieve a making current of 306 kA, which leaves not the least doubt about its current-carrying capacity in respect of the peak making current. Proof of the asymmetrical breaking current with an asymmetry of at least 50 % was gained at a symmetrical breaking current of 108 kA with an asymmetry of 52 %, as shown by the oscillogram in Fig. 4b. This yields an asymmetrical breaking current of 134 kA. The total break time measured in this t_0–t_3 amounted to 0·067 s, the highest value recorded during a series of eighteen load interruptions.

For a circuit-breaker—even when it is used as a transfer breaker—it is unusual for proof of its ability to overcome phase opposition to be established by testing at twice its rated voltage. The oscillogram in Fig. 4c shows that, under these conditions, it was able to handle breaking currents amounting to 30 % of the rated figure. In all the oscillograms in Fig. 4 the shape of the current trace between t_1 and t_3 provides ample evidence of the multiple extinction of the arc.

Other Breaker Models Based on the Same Concept

This method of constructing a circuit-breaker with a number of interrupters permits the design of breakers for rated voltages over 18 kV with rated breaking currents of 100 kA symmetrical and 130 kA asymmetrical. The number of interrupters per breaker pole will vary with the rated voltage and the manner in which the installation is connected. In many cases the breaker is triple-pole, for which three single-pole units may be employed. Particular advantages for mounting in metalclad enclosures are offered by single-phase breakers when the specification calls for phase separation by metal partitions throughout the installation.

The development of this kind of breaker for rated currents over 6000 A shows prospects of success, to judge by the results of heat runs performed. The breaking capacity remains unaffected. This type of breaker can be used not only as transfer breaker and for switching large transformers, but is ideal as a generator breaker in large power stations. The different possible designs and rating data allow breakers to be provided, for power stations with or without busbar systems, capable of meeting all requirements and affording maximum protection to equipment and personnel.

(KME) M. H. HILLENKAMP

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[3] IEC (International Electrotechnical Commission) Publ. 56–1, 1954. IEC specification for alternating-current circuit-breakers, Chap. 1.

LINE-DROPPING UNDER EXTREMELY SEVERE CONDITIONS IN THE 300-kV NETWORK OF THE QUEBEC HYDRO-ELECTRIC COMMISSION

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In the 300-kV network of the Quebec Hydro-Electric Commission, irregularities were occasionally experienced when lines at no-load were disconnected by airblast circuit-breakers. In certain cases the transient phenomena were extremely severe. With a view to rapidly restoring the dielectric strength of the extinction chambers, the breakers underwent a simple modification. The improved type of breaker was subsequently tested under very severe network conditions at voltages of 500 and 650 kV, respectively, and has operated satisfactorily ever since. Thus, once again, proof was obtained of the ability of type DC(V)F airblast breakers to disconnect e.h.v. lines at no-load.

BETWEEN 1953 and 1959 the Quebec Hydro-Electric Commission built a system of generating stations with power transmission lines between Bersimis and Montreal, as illustrated in Fig. 1 below. The sources of energy are located in the backwoods of the Bersimis region and are two enormous hydro-electric generating stations: Bersimis 1 having eight alternators with a total power of 1·2 million horsepower, and Bersimis 2 having five alternators totalling 800000 hp. From there the electrical energy is

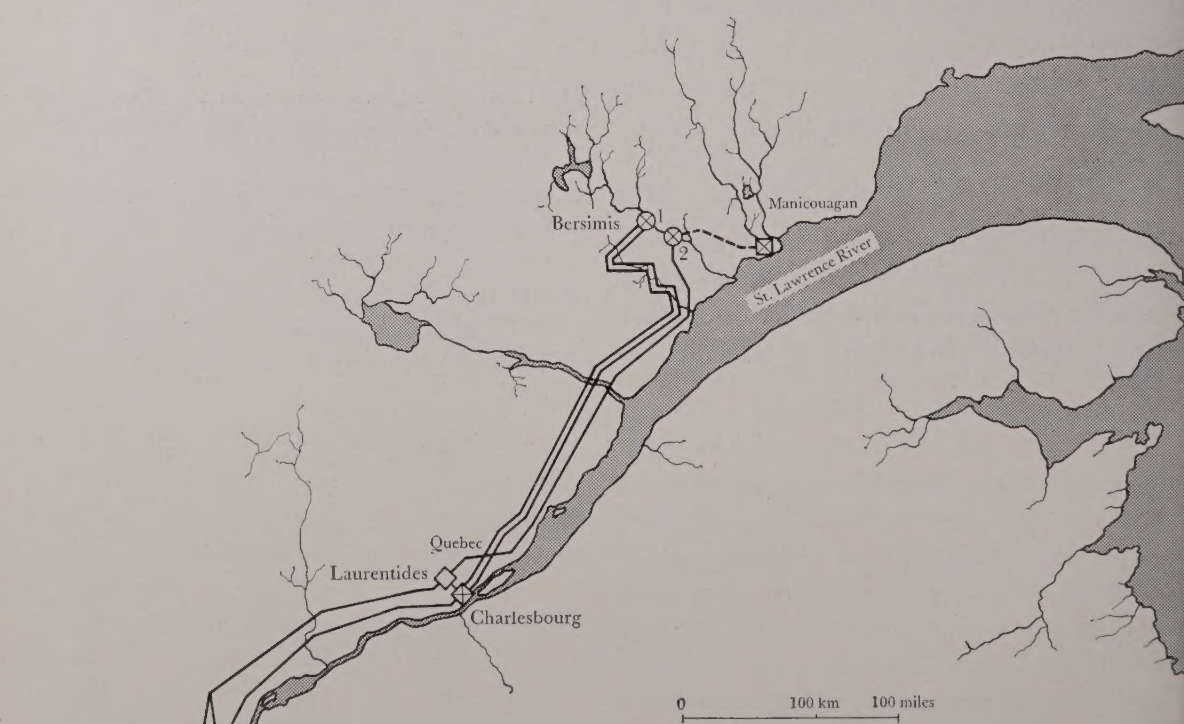

Fig. 1. – Sketch map showing the relative positions of the points mentioned in the 300-kV network of the Quebec Hydro-Electric Commission

⊗ = Hydro-electric generating plants ——— = 300-kV two-circuit line

⊠ = Main substations □ = Switching station – – – – = 300-kV single-circuit line

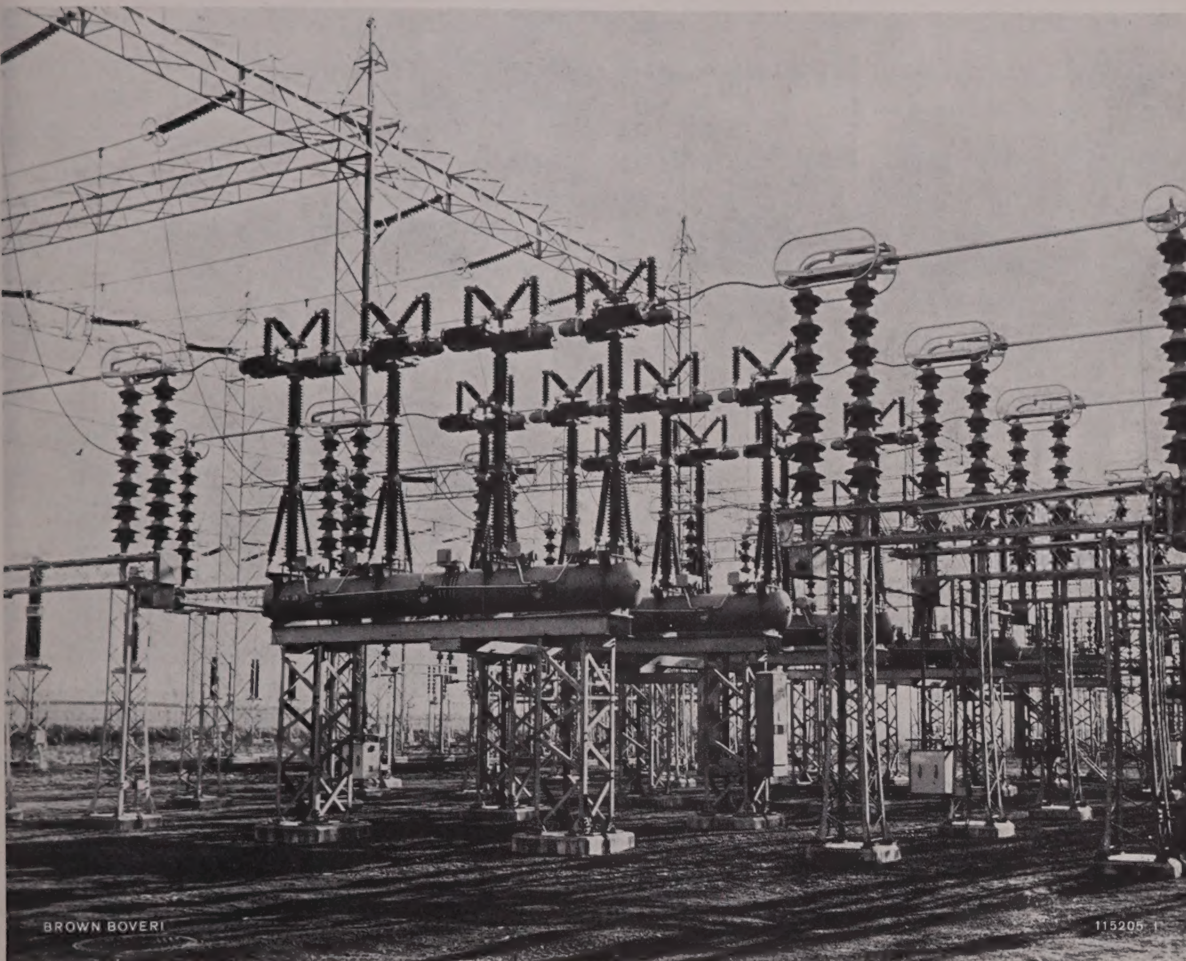

Fig. 2. – Brown Boveri airblast circuit-breaker in the Laurentides substation. Rated voltage 300 kV, rated current 1000 A, breaking capacity 7500 MVA symmetrical, 10 000 MVA asymmetrical

Following a very slight modification to the extinction chambers, this breaker successfully interrupted the 260 km length of line to Saraguay at no-load, up to a voltage of 500 kV. It was even able to repeat this performance when two of the interrupters on each pole were short-circuited.

transmitted over a system of several parallel lines at a normal service voltage of 315 kV, 60 c/s, to the Laurentides and Charlesbourg substations near Quebec, and from here at the same voltage on to Montreal.

For this system Brown Boveri supplied altogether 75 airblast circuit-breakers of the type DCVF for 300 kV. One such breaker is illustrated in Fig. 2. To ensure an ideal potential distribution when the main interrupting contacts are opened, the breakers are equipped with non-linear resistances. A few cycles later, when the resistance current has been interrupted, the potential distribution is controlled solely by capacitors. This type of breaker was originally fitted with ceramic capacitors, having low capacitance values. Later, in order to cope with voltages well above the rated figure, oil capacitors of higher capacity were fitted (as in Fig. 2).

Thousands of circuit-breakers of this and similar types are operating satisfactorily in Europe and other parts of the world [1]. For over ten years they proved ideal, particularly for the interruption of lines at no-load [2]. It therefore came as a great surprise when irregularities were suddenly experienced during precisely this switching operation in the network of the Quebec Hydro. Admittedly, of over

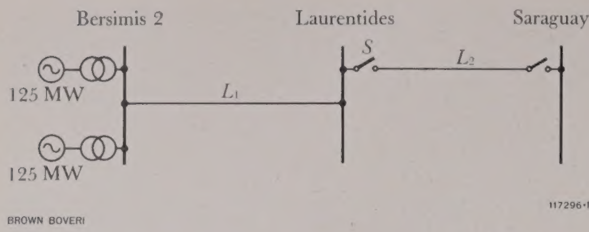

Fig. 3. – Schematic diagram showing the state of the network during the tests at Laurentides

L_1 = Line length 346 km
L_2 = Line 260 km long, dropped at no-load
S = Test breaker type DCVF 300 m 8 w, as illustrated in Fig. 2

1600 operations of this kind nearly all were executed without the least trouble. In some cases the irregularities were caused by network voltages well over the rated voltage of the breaker. In order to obtain an explanation of these phenomena, the Quebec

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Fig. 4. – Oscillograms of the interruption of a 260 km length of line at no-load

Before interruption the voltage at the input terminal of the breaker was 515 kV

a: Trace of oscillograph
b: Trace of cathode-ray oscilloscope
c: Voltage stress imposed on the first pole to quench (phase C)

U_A, U_B, U_C = Voltages between the input terminal and earth on phases A, B and C

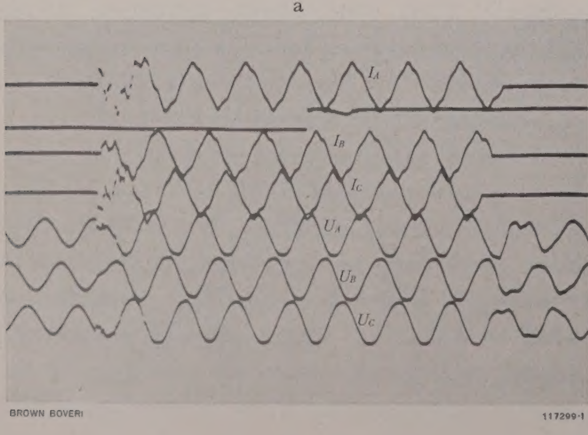
U_{AL}, U_{BL}, U_{CL} = Voltages between the line terminal and earth on phases A, B and C

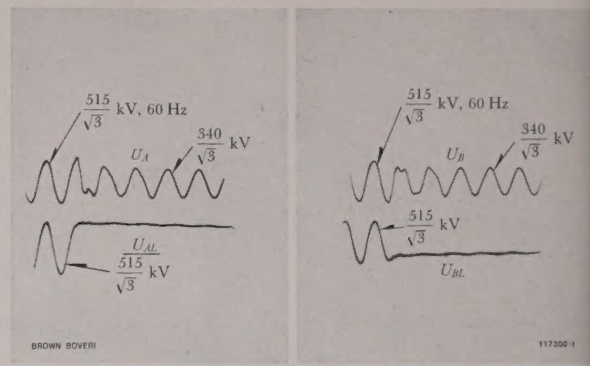
U_{CS} = Voltage across pole C (first to quench)

I_A, I_B, I_C = Phase currents

t = Time

a





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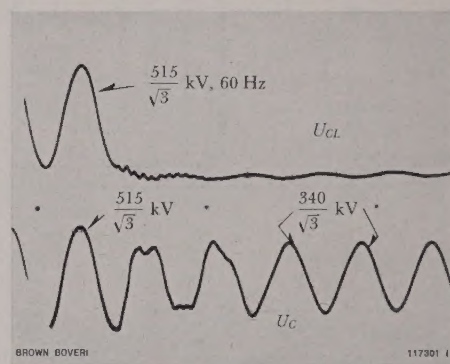

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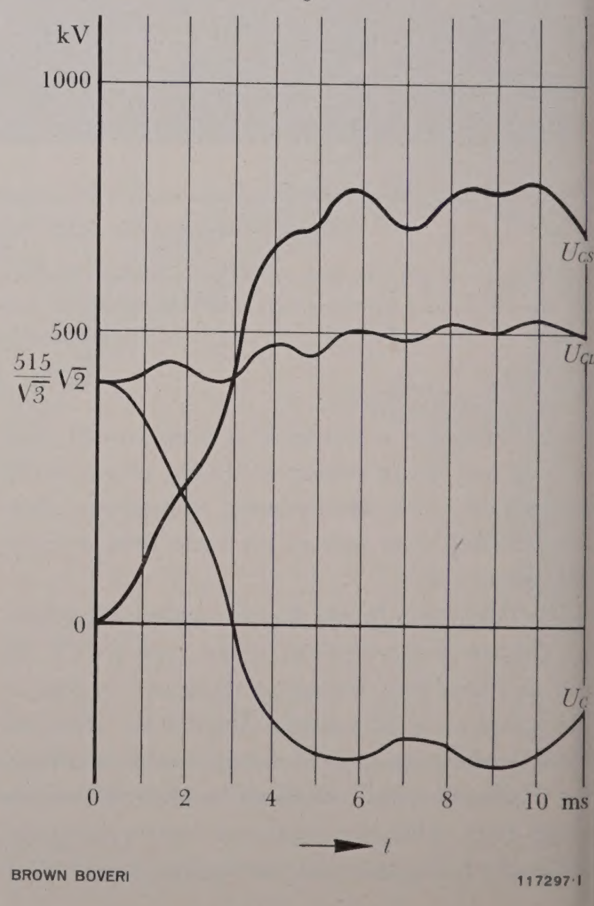

Hydro carried out a series of tests with oscillographic measurements in their network. These were based on a switching operation performed under extremely severe conditions.

Tests in Laurentides Substation

The state of the network at the time these tests were carried out is illustrated diagrammatically in Fig. 3. Two alternators and transformers in the power station Bersimis 2 are connected to the busbars in Laurentides by a separate line roughly 346 km long. From this busbar system, which was likewise isolated from the rest of the system, and unloaded, connection was made by means of an airblast breaker with the unloaded line to Saraguay, having a length of about 260 km; the breaker tested in Laurentides was closed and then opened again about 7 cycles (60 c/s) later, thereby producing a busbar voltage in Laurentides of up to about 500 kV before interruption.

As originally designed, the breaker could not cope with these conditions. Occasionally restriking occurred, and other complications. As may be seen in the oscillograms in Fig. 4, the voltage across the breaker pole rose within 4–5 ms from the interruption of the current to almost twice the peak value of power-frequency voltage between phase and earth, whereas under normal conditions with lines at no-load, this stress is not experienced for about half a cycle, i.e. 8–10 ms. The unusually severe voltage variation at Laurentides can be explained as follows. On the one hand the source of energy at Bersimis was relatively weak. The busbar voltage there was higher when the whole of the line right through to Saraguay was connected than it was when the section from Laurentides to Saraguay was disconnected. Hence, during the interruption in Laurentides, the voltage in Bersimis, and with it the voltage in Laurentides, fell by about 20 %. On the other hand, the Ferranti effect, i.e. the rise in voltage along the line, was greater in Laurentides when the whole line was connected through to Saraguay. On interrupting it in Laurentides the busbar voltage consequently dropped by a further 20 %. The whole voltage drop at the input terminal of the breaker in Laurentides, amounting to roughly 40 %, took the form of a damped oscillation with a natural frequency of 150 c/s (Fig. 4).

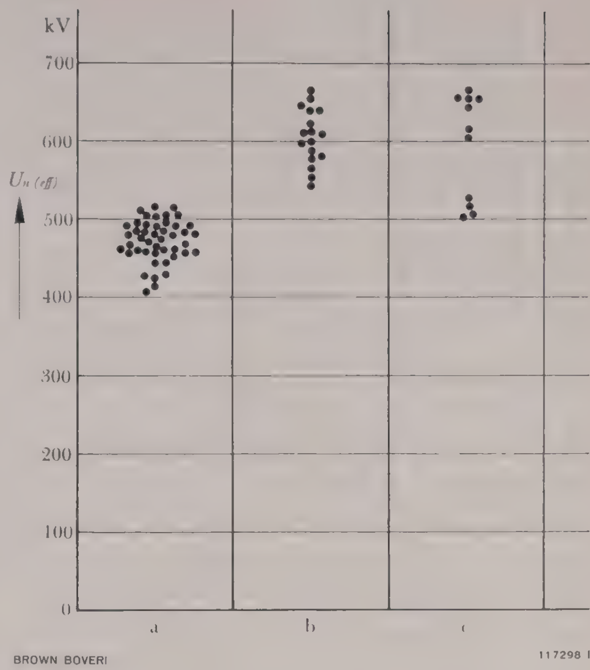

Fig. 5. – Summary of the tests results with the improved breaker

Each point represents a three-phase interruption

U_n = Driving voltage

a: Interrupter I, 8 interrupters per pole

b: Interrupter I, 6 interrupters per pole
The points plotted represent the voltages converted proportionally for 8 interrupters

c: Interrupter II, 6 interrupters per pole
The points plotted represent the voltages converted proportionally for 8 interrupters

All switching operations were performed without restriking occurring.

The only remedy was to increase the rate at which the dielectric strength of the breaker pole was restored, so as to enable it to withstand the rapidly rising recovery voltage and so prevent restriking. This was achieved by improving the flow of air in the extinction chambers, by quite simple means. The lower limit of the scatter band of the electric strength of the gap between the extinction contacts, during their separation, was more than doubled.

Another factor which was improved was the simultaneity of the interrupting actions of the contacts switching the resistors. With these modifications and, once more, using the oil capacitors to obtain more uniform voltage distribution, it was

Line-dropping tests performed with the improved breaker

Number of interrupters per pole	Improved interrupter I or II	Voltage at terminal on busbar side of breaker in Laurentides		Current interrupted	Number of interruptions
		just before interruption kV	3–5 cycles after interruption kV	A	
8	I	410–430	267–287	162–180	4
8	I	430–460	298–322	187–222	14[1]
8	I	460–490	306–355	209–271	18[1]
8	I	490–515	302–374	249–303	9
6	I	410–430	285–289	175–195	5[1]
6	I	430–460	293–321	183–213	5[1]
6	I	460–490	315–350	201–278	6
6	I	496	354	292	1
6	II	423	283	190	1[1]
6	II	430–460	288–296	182–197	3
6	II	460–490	318–329	229–241	2[1]
6	II	490–500	348–350	286–290	5[2]

[1] During one operation of this breaker re-ignition occurred. The latest case of re-ignition occurred 1·5 ms after the current had been interrupted. Re-ignitions, which occur within ¼ of a cycle (of the service frequency) after the current has been interrupted are insignificant for the process of interruption, in contrast to restrikes.

[2] During this group of operations two cases of re-ignition occurred, after 0·8 and 0·9 ms, respectively.

anticipated that the breaker would be able to withstand the difficult conditions imposed by this switching action in Laurentides up to at least 450 kV.

The tests were repeated in November 1960, yielding very successful results. These results are shown in the above Table and in Fig. 5. Having successfully performed all switching operations up to over 500 kV using a breaker with eight interrupters per pole, and since the line voltage could not be increased any further, two interrupters were short-circuited and the switching operations repeated with only six interrupters per pole. In the course of these tests two slightly different arrangements of the interrupters were tried out, as shown by the series of tests b and c in Fig. 5. These tests were also successful. If the results obtained are converted proportionally for a breaker with eight interrupters per pole, it follows that this breaker can reliably withstand the conditions imposed by this severe operation up to a phase-to-phase input voltage of 650 kV. This is all the more noteworthy when it is borne in mind that the breaker was originally guaranteed for a service voltage of only 315 kV.

Thus it was proved once more that the airblast circuit-breaker type DC(V)F is ideally suited to the interruption of e.h.v. lines at no-load.

(KME) P. BALTENSPERGER

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10000 MILES OF HIGH-VOLTAGE TRANSMISSION LINES IN CANADA EQUIPPED WITH MODERN BROWN BOVERI POWER LINE CARRIER SYSTEMS

621.398.052.63

Eight years ago, in 1953, Brown Boveri installed their first power line carrier (PLC) system in Canada, since when they have developed into the leading suppliers of carrier equipment in this part of North America. Modern methods and techniques, a very complete manufacturing programme and far-sighted, technically outstanding project engineering all helped in the achievement of this position. The excellent performance of the equipment in service has been an essential factor in securing customers' confidence, particularly in view of the long distances and the maintenance problems involved.

A brief review of the installations delivered and ordered between 1953 and 1961 yields the following picture:

- More than 100 PLC links, with a total of 370 cabinets; on the average each of the above links carries three different kinds of information simultaneously, e.g. voice, control and telemetering signals.
- Brown Boveri installations are to be found in all Canadian provinces from coast to coast, except Prince Edward Island; the list includes Newfoundland, Labrador and the Northwest Territories in the sub-arctic part of the country.
- The main customers are nineteen power utilities—seven of which are government organizations, the other twelve being private undertakings.
- The material already supplied and on order covers 10000 miles of transmission lines with voltages ranging from 25 to 380 kV; this mileage represents three times the breadth of Canada from east to west.

IN 1953 a report was published on the first Brown Boveri power line carrier installation in Canada, which is installed in the 230-kV system of the Shawinigan Water and Power Company between Isle Maligne and Quebec City, where it is rendering excellent service for voice communication, transfer-trip protection relaying,[1] and telemetering [1]. This first, modest business success induced the Company to analyse and study the Canadian market more closely, and to try to interest a broader clientele in PLC equipment. The enormous construction programme for power plants and high-voltage transmission lines across the vast Canadian territory offered the best prospects for this undertaking, considering the fact that the construction of a power system automatically calls for communication facilities. Nevertheless, it was essential to consider that practically all Canadian power utilities had been using PLC equipment of American origin over the past twenty years and had thus adopted North American methods which differ appreciably from European practice.

In contrast to the American and Canadian practice of almost exclusively using PLC equipment with double-sideband amplitude modulation (DSB) or frequency modulation (FM), Brown Boveri adopted more than ten years ago the amplitude-modulation single-sideband (SSB) technique, which has proved to be most successful. In addition, the majority of North American PLC equipment is of the so-called "single-purpose" type, which means that it can only be used for the transmission of a single information such as voice, telemetering, or remote control signals, etc. If several forms of information have to be transmitted simultaneously over one and the same transmission line, it is therefore necessary to provide several parallel PLC links. In contrast to the above, the design of Brown Boveri PLC systems has always been guided by the aim of rationalizing the utilization of the available frequency spectrum by transmitting a maximum of information within a minimum of bandwidth. This trend has thus led to the development of "multi-purpose" equipment, which not only permits the previously mentioned forms of information to be transmitted simultaneously, but also in a much narrower frequency band. However, full advantage of this multi-purpose equipment can only be taken if all signals in both directions of a PLC circuit can be transmitted continuously. This leads automatically to the

[1] Wherever this term appears in this article, it is understood to imply "permissive transfer tripping".

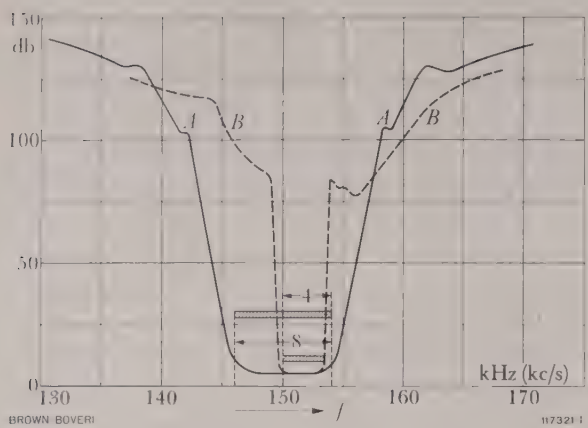

Fig. 1. – Comparison between double-sideband and single-sideband receiver selectivity

A = Double-sideband
B = Single-sideband

Abscissae: Frequency f in kc/s
Ordinates: Attenuation in db

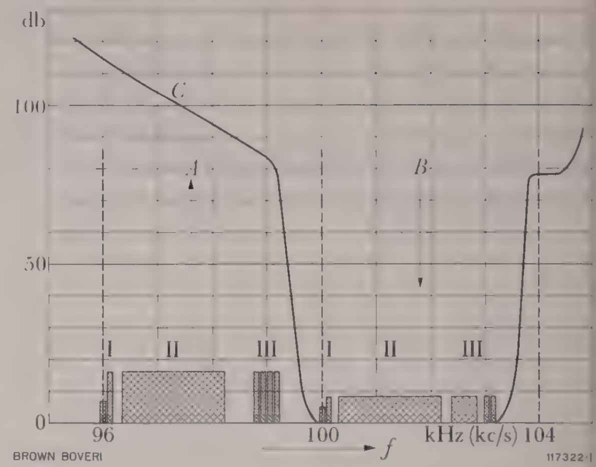

Fig. 2. – Brown Boveri single-sideband equipment permits the transmitting and receiving channels to be adjacent

A = Transmitting channel
B = Receiving channel
C = Receiver selectivity
I = Ringing or dialling
II = Voice
III = Superposed signals (supervisory control, etc.)

Abscissae: Frequency f in kc/s
Ordinates: Attenuation in db

"duplex" technique, the only type of communication employed in Brown Boveri fixed installations; whereas the great majority of North American PLC systems still use the "simplex" method which only permits alternate transmission and reception, a feature which in no way meets the requirements of a modern communication system.

To simplify understanding of the technical problems involved, a few fundamental questions will now be enlarged upon.

Brown Boveri Single-Sideband System

The basic theory of SSB is to transmit only one of the two sidebands and to eliminate the other because the intelligence is all contained in one sideband. The Brown Boveri SSB system makes use of this principle by transmitting only the upper sideband and a reduced or partly suppressed carrier, the latter as a pilot link for demodulation, automatic volume control, and carrier channel supervision. The transmitted carrier frequency band thus has exactly the same width as the original message in its audio form, in contrast to DSB and FM where a band twice as wide as the audio range is required. In addition, the SSB system offers a noticeable improvement in selectivity (see Fig. 1). Apart from the space-saving aspect it is clear that one sideband contains less noise than two, and that the efficiency of an SSB transmitter is about twice as good as for DSB and FM because the transmitter power output is used to transmit only one sideband.

A most essential feature of the Brown Boveri SSB equipment is that the transmitting and receiving channels of a duplex link can be placed directly adjacent (see Fig. 2). With this feature we obtain the following gross bandwidths:

a. 8 kc/s by using 4-kc/s PLC equipment in each direction, applicable for the transmission of voice and up to seven superposed narrow-band channels for supervisory control, telemetering, protection relaying, teletype, etc.

b. 5 kc/s by using 2·5-kc/s PLC equipment in both directions, applicable for the transmission of voice only.

A comparison between the frequency spectrum occupation of DSB and FM equipment and that of Brown Boveri SSB equipment is shown in Fig. 3. The DSB and FM equipment not only require 8 kc/s in each direction, but in addition require a minimum spacing of 12 kc/s between the carriers of the transmitting and receiving channels, so that

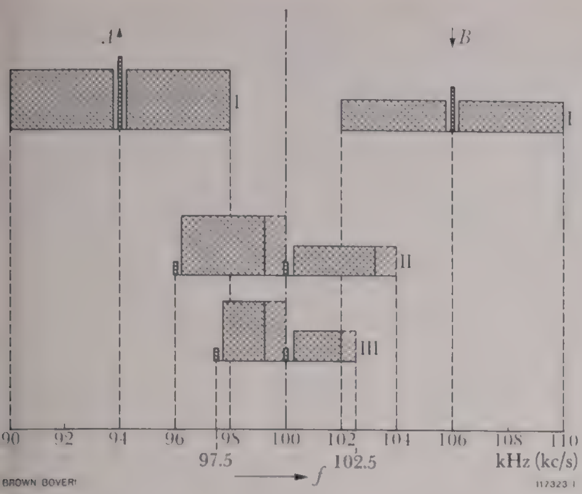

Fig. 3. – Frequency spectrum occupation of double-sideband or FM equipment compared with Brown Boveri single-sideband equipment

A = Transmitting channel
B = Receiving channel
I = Double-sideband or FM
II = Single-sideband (4-kc/s multi-purpose equipment)
III = Single-sideband (2·5-kc/s equipment for voice only)

Abscissae: Frequency f in kc/s

a total of 20 kc/s is necessary to accommodate one duplex link in contrast to 8 or 5 kc/s for SSB equipment.

This leads to another fundamental discrepancy between American and European practice. Our planning and design of PLC systems is governed by the aim of saving as much frequency space as possible and therefore all information (voice, relaying, telemetering, supervisory control, etc.) are fed into a single carrier link of the 4-kc/s multi-purpose type. The voice band is cut at 2200 or 2000 c/s and the remaining space up to 3240 c/s used for relaying, telemetering, supervisory control, etc. Consequently all services required between two or more points of a system are accommodated within 4 kc/s in one direction or 8 kc/s in both directions. This is an extremely flexible method because, even if a link is initially used for voice only, telemetering, supervisory control, and relaying can be added at any time without any change in the basic equipment.

In particular, this method offers the great advantage that all line coupling elements and wave traps can be left unchanged, an asset which can bring about considerable savings and operational advantages.

Fig. 4. – 20-W single-sideband transmitter-receiver set

The selector switches and push-buttons are for checking tubes, anode and filament voltages, and carrier output signal. Cabinet door removed.

The "multi-purpose" method described shows clearly that all signal transmission is in the hands of a single engineering department, responsible for planning, engineering, and co-ordination of carrier signal transmission for all possible services. Only in this manner is it possible to achieve an appropriate and rational planning and design of modern PLC systems (see Fig. 4 and 5).

Rapid-Cyclic Electronic Telemetering System

Governed by the same considerations as outlined above a telemetering system has been developed, differing from those generally used in North America and which is again guided by the aim of maximum

Fig. 5. – Testing single-sideband carrier equipment in the factory

Doors and front plates of chassis removed.

utilization of the frequency spectrum—i.e. minimum band occupation. This is the rapid-cyclic electronic telemetering system, which accommodates up to 38 measurands in a single audio channel with simultaneous and continuous indication of all measurands. Unlike the more common wide-band frequency multiplex systems for multiple measurand transmission, this system operates on the time multiplex principle.

The advantage of the time multiplex over the frequency multiplex system is that, at a given instant, only one measurand is being transmitted; the available transmission energy is thus not split up among a large number of channels. Also the bandwidth needed is not affected by the number of measurands and, for more than about four measurands, is smaller than that occupied by the frequency multiplex system.

Each function to be metered or indicated in a remote station is converted by a variable inductance into a given frequency varying in proportion with the metered quantity. These individual frequencies, produced by separate, permanently oscillating tone generators, are successively scanned electronically by a "Decatron" (10-step cold-cathode thyratron) and transmitted to the receiving end. The receiving scanning device is synchronized with that of the transmitter by two separate signals, one for synchronization and one for phase control.

Each measurand at the receiving end is electronically stored at the output level at which it was last received. The following scanning cycles are required if the measurands are all transmitted by one channel: 0·6 s for 8 measurands, 1·2 s for 18, 1·8 s for 28 and 2·4 s for 38.

The a.f. bandwidth required is $\pm$ 8 % of the mean channel frequency (400 c/s for an audio channel having a centre frequency of 2500 c/s). This system permits the visual display of numerous functions of a

Fig. 6. – Map of Canada showing all Brown Boveri power line carrier installations supplied since 1953

Altogether there are 105 links, mainly of the multi-purpose type, shown in simplified form.
N.B. = New Brunswick N.S. = Nova Scotia N.F. = Newfoundland

•—• Single links •══• Two or more parallel links

controlled station simultaneously, and is consequently superior to a system where indication is "as called for", and more economical than a multichannel continuous system. To transmit 38 continuous readings with frequency multiplex may require anything between 6 and 20 kc/s, depending on the type of equipment used. This is 15 to 20 times more than the mere 400 c/s of the cyclic system described.

Brown Boveri Power Line Carrier Installations in Canadian Power Systems

Having described the essential features and advantages of the two most important Brown Boveri products in the PLC field, some of the major installations in Canada will now be discussed, referring to the sketch map of Canada (Fig. 6).

Systems in Nova Scotia and New Brunswick

Beginning in the eastern part of the country, there is the extensive PLC network of the maritime provinces Nova Scotia and New Brunswick where, since 1956, a total of eleven SSB, two DSB and two wave-changeover links have been supplied to the New Brunswick Electric Power Commission (see Fig. 7), the Fraser Companies, Nova Scotia Power Commission, and the Nova Scotia Light and Power Co.

An additional SSB link connects this large network with the American power utility, Maine Public Service Co., across the border.

All five companies are partners in a very large 69/138-kV grid to be realized in several stages, which will ultimately involve about 30 generating stations and substations. The PLC system supplied

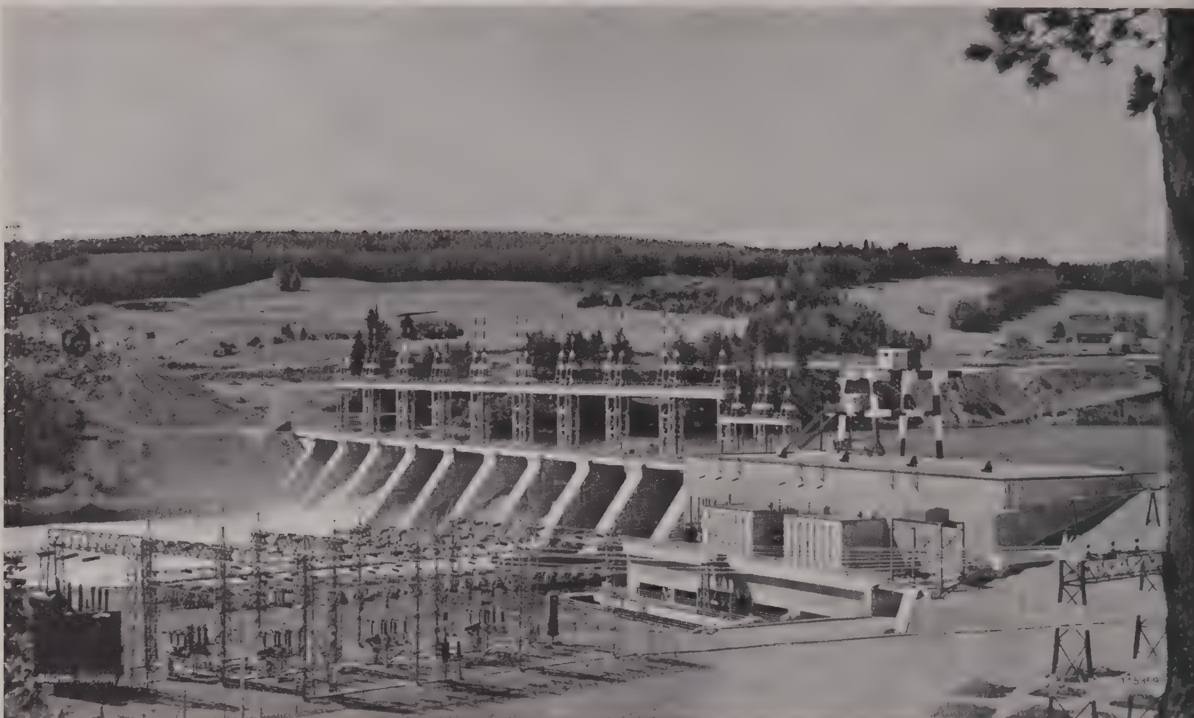

Fig. 7. – Beechwood generating station of the New Brunswick Electric Power Commission, one of the main centres in the extensive power line carrier network supplied by Brown Boveri

(Courtesy New Brunswick Electric Power Commission)

Fig. 8. – 300-kV Bersimis River Power Development of the Quebec Hydro-Electric Commission

Phase-to-phase (inter-system) carrier line coupling, consisting of 300-kV coupling capacitors (also used as potential devices) and 1000-A wave traps. The six current transformers were also supplied by Brown Boveri.

(Courtesy Quebec Hydro-Electric Commission)

so far interconnects 16 stations for duplex voice communication with fully automatic dialling,[2] the longest possible chain covering a distance of 375 miles with a total of nine links connected in series.

A special priority cut-in feature enables the three load dispatching centres at Fredericton (capital of New Brunswick), Halifax (capital of Nova Scotia), and Trenton to break into an existing telephone conversation simply by depressing a button on the telephone set. The two parties conversing can thus be instructed to replace their handsets, whereupon the desired connection is automatically established without dialling having to be repeated. Only one of the two first-mentioned parties has to replace his handset to release the circuit.

The majority of the 14 SSB and DSB links are used not only for voice but also for the transmission of superimposed telemetering, supervisory control, and protection relaying signals. For this purpose an appreciable number of audio-frequency shift

[2] Automatic telephone equipment manufactured by Albiswerk, Zürich, Ltd.

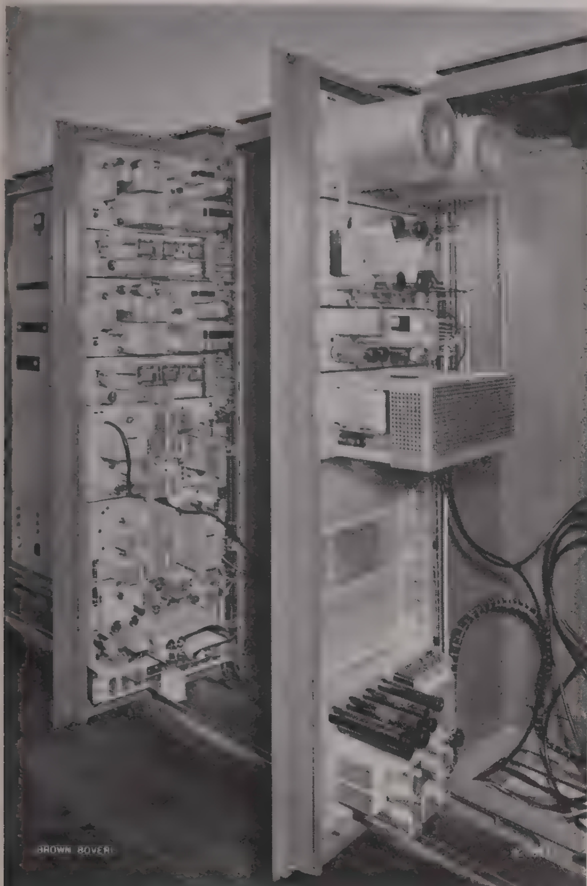

Fig. 9. – Part of one of the seven terminal stations in the Bersimis power line carrier system

The two open cabinets contain single-sideband and frequency-shift equipment for transfer-trip protection relaying (left-hand side) and the 100-W power amplifier (right-hand side).

Fig. 10 (above right) – 380-kV Chute-des-Passes Power Development of the Aluminum Company of Canada

Phase-to-phase (inter-system) carrier line coupling, consisting of 380-kV coupling capacitors (also used as potential devices) and suspended 2000-A wave traps.

(Courtesy Aluminum Company of Canada; see also front cover)

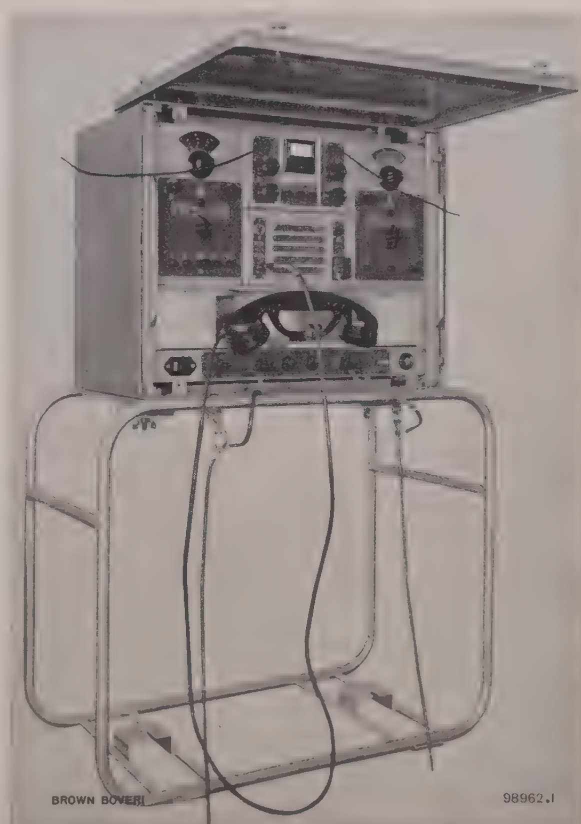

Fig. 11. – 2-W midget type carrier set for simplex voice communication between mobile line patrols and the terminal stations of a carrier link

Such units are in use along the 380-kV Chute-des-Passes line, further units of similar construction along two 161-kV lines of the Quebec Hydro-Electric Commission.

channels is provided, as well as four rapid-cyclic telemetering installations and two supervisory control systems (manufactured by Albiswerk Zürich Ltd.);

Fig. 12. – St. Lawrence (Cornwall) generating station, a gigantic joint undertaking of the Hydro-Electric Power Commission of Ontario and the Power Authority of the State of New York

The plant interconnects the Canadian shore in the foreground with the American shore across the St. Lawrence River. Each half of the plant contains 16 generators, the total installed capacity of the station being 1800 MW. St. Lawrence is the centre of three Brown Boveri carrier links, one of which leads to the province of Quebec (Beauharnois generating station, Fig. 13).
(Courtesy Hydro-Electric Power Commission of Ontario)

the latter are used for the remote control of the two hydro-electric generating stations, Sissiboo Falls with 7·5 MW, and Weymouth Falls with 11·25 MW, over two of the previously mentioned PLC links.

The greatest concentration of Brown Boveri PLC systems is found in the province of Quebec. Out of a total of 38 links supplied to Quebec Hydro-Electric Commission, Shawinigan Water and Power Company, Aluminum Company of Canada, and James MacLaren Company, the following two networks are of particular interest: The 300-kV Bersimis River Power Development of Quebec Hydro-Electric Commission and the 380-kV Chute-des-Passes Power Development of the Aluminum Company of Canada. In view of the high transmission-line voltages and in some cases the very long distances, especially difficult signal transmission problems were encountered in both systems, which could only be solved with SSB equipment.

300-kV Bersimis System

The Bersimis system with the two hydro-electric generating stations Bersimis I and II, located on the Bersimis river some 400 miles north of Montreal, carries energy towards Quebec City and Montreal for feeding into the huge interconnected system of Lake St. John, Shawinigan and Quebec Hydro/Beauharnois. All the 300-kV transmission lines consist of aluminum-copper conductors, with a diameter of only 1·54 in. which cause considerable losses for the transmission of carrier signals. A further aggravation is caused by the extremely severe weather conditions which prevail in the geographical area of the Bersimis system, particularly in the northern part where, during a winter period of six months, the noise level and the losses are increased by hoar-frost, freezing rain and frequent snowstorms. Considering the fact that, apart from several shorter links, there are no less than six direct PLC circuits covering a distance of 240 miles and five circuits over 150 miles, and that channel losses of up to 50 db are encountered, the reason for using 100-W SSB equipment on all these long circuits becomes obvious. All Brown Boveri installations which were commissioned in several stages between 1956 and 1959 are giving excellent performance for voice

Fig. 13. – Beauharnois generating station of the Quebec Hydro-Electric Commission, located on the St. Lawrence River near Montreal

With an installed capacity of 1680 MW, Beauharnois is the largest generating station in Canada; it contains 37 generators and has a length of 2836 feet. Four Brown Boveri power line carrier links interconnect Beauharnois with the stations Mgr. Emard (remote-controlled substation), Atwater, Cedars, and St. Lawrence, Ontario.

(Courtesy Quebec Hydro-Electric Commission)

Fig. 14. – Kelsey generating station of the Manitoba Hydro-Electric Board, located on the Nelson River in the far north of the province, close to the vegetation limit

When finally completed the total capacity of Kelsey will be 240 MW with six hydro-electric generators of 40 MW each; at present there are five units in operation. Kelsey is completely remote-controlled from Thompson over a 60-mile 138-kV double-circuit line, and is one of the largest remote-controlled power plants in the world. Brown Boveri engineered and supplied the entire carrier, telemetering, and control system.

(Courtesy Manitoba Hydro-Electric Board)

communication and transfer-trip protection relaying [3] (see Fig. 8 and 9).

380-kV System of the Aluminum Company of Canada

The second significant PLC system in the Province of Quebec belongs to the Aluminum Company of Canada and consists of four parallel SSB links of 20 W each over the 100-mile 380-kV double circuit between the two hydro-electric generating stations Chute-des-Passes and Isle Maligne. The transmission lines consist of ACSR double-bundle conductors of 1·099 in. diameter with a spacing of 16 in. The four SSB links are used for voice communication, transfer-trip protection relaying, telemetering and teletype. To achieve better reliability, the protection relaying signals are always transmitted over two SSB links in parallel, which clearly shows the great advantage of multi-purpose equipment. Other important features of this PLC system are four band-tuned wave traps for a rated current of 2000 A and with an inductance of 0·165 mH; the blocking range is 120–200 kc/s with a minimum blocking impedance of 400 ohms. In contrast to the rather clumsy and bulky method of mounting wave traps horizontally on insulator stacks, as practised in North America, these 2000-A traps with a weight of 1750 lb. are suspended vertically on insulator strings in accordance with normal Brown Boveri practice (see colour plate on front cover and Fig. 10).

All coupling capacitors are built as capacitive potential devices and are used for carrier line coupling, as well as for voltage measurement. In place of the appreciably more expensive magnetic

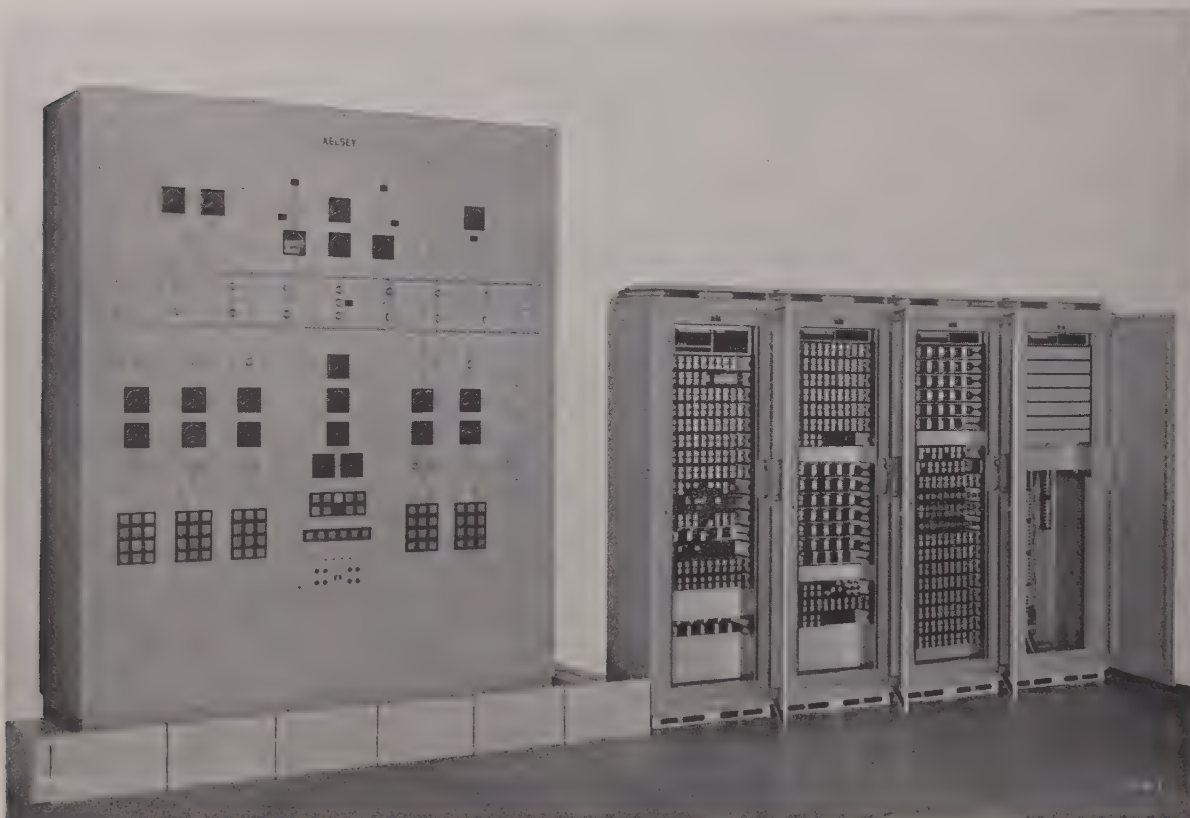

Fig. 15. – Master control board for Thompson (left) and supervisory evaluator panels for the slave station at Kelsey (right) photographed in the factory before shipment. The master board contains all control and supervisory relays; the mimic diagram on the front contains all telemetering instruments, control and indication switches, as well as 12 alarm annunciators for each generator. The latter indicate low oil levels, over-temperatures, etc., while the remote and local common alarms are indicated by the group of annunciators in the middle section of the panel. The telemetering instruments indicate the active power, reactive power, and excitation current of all generators, the position and limits of turbine guide vanes, the water levels of inlet and outlet, sluice-gate positions, etc.

Fig. 16. – "Queen Elizabeth" generating station of the Saskatchewan Power Corporation in Saskatoon

For this power plant Brown Boveri supplied not only a 75-MW condensing steam turbine, but also an extensive power-line carrier installation. Saskatoon is the load dispatcher of the entire northern power system and the centre of eight single-sideband carrier links for voice communication with automatic dialling, telemetering, supervisory control, teletype, and protection relaying. (Courtesy Saskatchewan Power Corporation)

voltage transformers, there are altogether eight capacitive potential devices installed at the 380-kV busbars of the two power stations, where they are used for voltage measurement, synchronization and for the power supply to the high-speed distance relays, also supplied by Brown Boveri.

Systems of the Hydro-Electric Power Commission of Ontario

In the Province of Ontario there are two extensive PLC systems in operation in the network of the Hydro-Electric Power Commission of Ontario, the largest Canadian power utility. In the eastern part of the province is a system consisting of seven SSB links for voice communication, operating on the 230-kV system in the area Toronto–Ottawa–St. Lawrence (Cornwall), as well as on the tie-line between Ontario–Hydro (St. Lawrence generating station) and Quebec–Hydro (Beauharnois generating station). The St. Lawrence generating station (see Fig. 12) became internationally known in connection with the construction of the gigantic "St. Lawrence Seaway" between the inland harbour Montreal and the Great Lakes, while Beauharnois (see Fig. 13) with an installed capacity of 1680 MW is known as the largest Canadian generating station. The distance Toronto–Beauharnois (Montreal) amounts to 375 miles and is bridged by four SSB links in series.

In the western part of the province the same power utility is operating another extensive PLC system consisting of seven SSB links. It covers the area between Port Arthur on Lake Superior and the province of Manitoba, where interconnection with the network of the Manitoba Hydro-Electric Board is established in the Seven Sisters generating station.

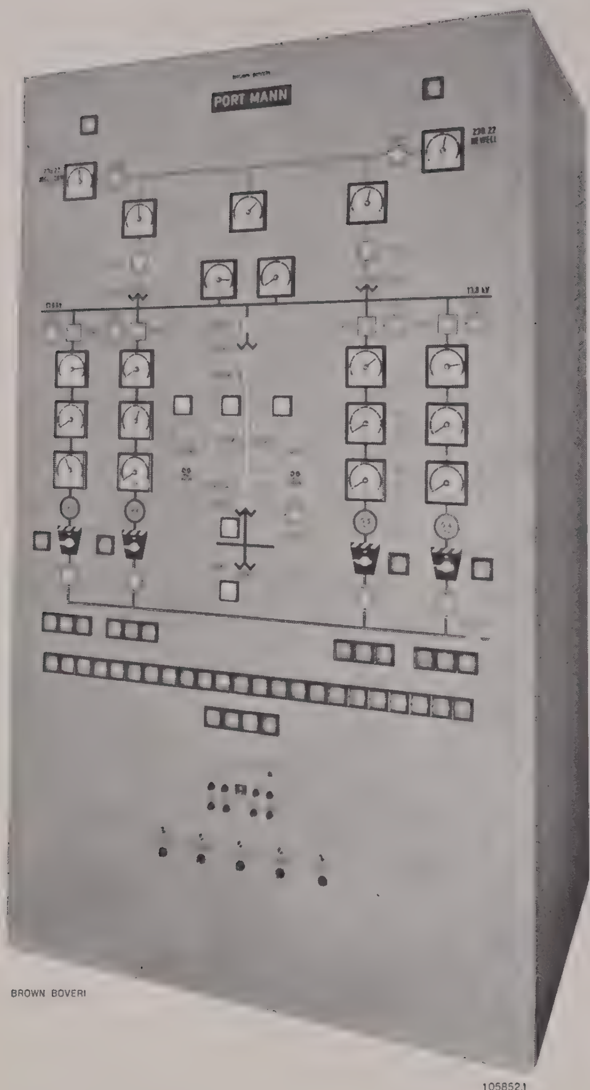

Fig. 17. – Master control board with mimic diagram in the Vancouver load dispatching centre, for remote control of the 110-MW Port Mann gas-turbine generating station of the British Columbia Electric Company

Port Mann is at present the largest gas-turbine power plant in the world.

System of the Manitoba Hydro-Electric Board

In the Central Canadian province of Manitoba, Brown Boveri have supplied a PLC system consisting of seven SSB links to the Manitoba Hydro-Electric Board. The most important scheme, to be described below, operates between the hydro-electric generating station at Kelsey, located on the Nelson river 440 miles north of Winnipeg, and the Thompson nickel mine of the International Nickel Company of Canada. Kelsey (see Fig. 14) is completely remote-controlled from Thompson over a 60-mile 138-kV double-circuit line. The ultimate capacity of Kelsey will be 240 MW with a total of six hydro-electric generators of 40 MW each; to date there are five generators in operation.

The Brown Boveri installation involves two parallel SSB links for duplex voice communication with superposed channels for protection relaying, supervisory control and telemetering. A rapid-cyclic telemetering system permits the transmission of 12 continuous measurands and, through the intermediary of the supervisory control equipment, another 38 optional measurands "as called for". The supervisory control equipment (manufactured by Albiswerk Zürich Ltd.) has in its present state the following capacity:

80 double commands ("on-off") with back indication
30 "raise-lower" functions
7 position indications, and
73 alarms (see Fig. 15).

Brown Boveri were able to secure this substantial and significant order against not less than 10 competitors from North America and Europe. This was made possible by clear technical superiority, since the modern frequency-saving methods of single-sideband transmission and rapid-cyclic telemetering allow the entire telemetering and supervisory control programme, as well as the protection relaying signals for the two high-voltage transmission lines to be transmitted simultaneously over both of the parallel SSB links, without requiring any additional material. Consequently, the reliability could be increased considerably. In spite of duplicating all supervisory control, telemetering and protection relaying channels, the total gross bandwidth for the transmission of this extensive programme is only 16 kc/s, whereas competitors had proposed schemes with more than twice this bandwidth, but without duplication of the above-mentioned channels.

System of the Saskatchewan Power Corporation

Further west from Manitoba is the province of Saskatchewan, where an extensive PLC system was supplied to the Saskatchewan Power Corporation. To date this network represents the most modern and complex scheme in operation in North America

and is thus an outstanding reference for Brown Boveri. The PLC network consists of 20 SSB links, covering the entire 72/138-kV system, involving six generating stations and 10 substations. The whole voice communication network is equipped with a fully automatic dialling system (manufactured by Albiswerk Zürich Limited), which permits any of the 16 stations to be dialled from any other station. The two load dispatching centres, Saskatoon in the northern part (see Fig. 16) and Boundary Dam in the southern part are equipped with a priority cut-in feature, which enables the two load dispatchers to break into any existing conversation. Another special feature is the use of so-called "automatic free-line selectors" in all those places where a connection between two stations can be established via two different routes; if one route is engaged, these selectors automatically establish the connection via the alternative route.

This province-wide network, which was recently also extended by three Brown Boveri VHF radiotelephone links, is quite an outstanding example of the application of the multi-purpose technique, since on all 20 SSB links several other intelligences are transmitted above the voice band. For example, all 138-kV links are equipped with audio-frequency shift channels for protection relaying; additional frequency-shift channels are used for a rather complex teletype system, which interconnects the generating stations Prince Albert, Saskatoon, Unity, Kindersley and Boundary Dam, as well as Regina, the capital of the province and headquarters of the Saskatchewan Power Corporation. The teletype system operates in such a way that every message transmitted from any of the above-mentioned stations is automatically received and registered in all other stations. The substations at North Battleford, Wolverine and Beatty are remote-controlled from Saskatoon; those at Pasqua (Moose Jaw) and Weyburn from Boundary Dam. For this purpose, five Albiswerk supervisory control installations were supplied which operate over Brown Boveri PLC links. A total of four rapid-cyclic telemetering systems are provided to transmit a substantial number of measurands from Wolverine, Kindersley and Hawarden to Saskatoon, and from Regina to Boundary Dam.

Fig. 18. – Rear view of the master control board in the Vancouver load dispatching centre

Top left: Rapid-cyclic telemetering system for 18 measurands
Top right: Frequency-shift channels

Bottom left and right: Supervisory control equipment

The PLC network described is interconnected with the previously mentioned system of the Manitoba Hydro-Electric Board by an SSB link over the inter-provincial tie-line between Boundary Dam and the Brandon generating station in Manitoba. Over this link, it is possible to establish a long-distance conversation between Winnipeg in Manitoba and Kindersley in Saskatchewan over a distance of 780 miles and over seven SSB links in series. It goes without saying that all other stations of the described network can be reached from Winnipeg. The three load dispatching centres Winnipeg, Boundary Dam and Saskatoon are thus in a position to communicate with each other and to control the energy exchange between the two provinces.

Systems in Western Canada

In the province of Alberta, in the sub-arctic Northwest Territories and in British Columbia, there are five Brown Boveri PLC installations. To conclude this article the scheme in British Columbia will be briefly described. It interconnects the Port Mann gas-turbine generating station of the British Columbia Electric Company, Vancouver, with Ingledow substation and the load dispatching centre in Vancouver (see Fig. 17 and 18). As in the case of Kelsey (Manitoba) Brown Boveri were entrusted with the supply of the entire communication and control system for the remote control of Port Mann from Vancouver.

The scheme consists of one SSB link over the 230-kV transmission line Port Mann–Ingledow, a rapid-cyclic telemetering system for 18 measurands and an Albiswerk supervisory control installation. The PLC link from Port Mann to Ingledow is continued over a microwave radio system of another make to Vancouver. Port Mann, with four Brown Boveri gas turbines totalling 110 MW, is to date the largest gas-turbine generating station in the world and, at the same time, the largest remote-controlled gas turbine plant in existence [4].

O. KREIS

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A NEW METHOD OF SUPPRESSING THERMIONIC EMISSION FROM THE GRIDS OF TRANSMITTING TUBES

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This article describes a new method of producing grids for transmitting tubes, enabling them to carry heavy loads with very low thermionic emission. After discussing the grid materials which have been used up to now, the author deals with the method of manufacturing the new grids, by electrolytic deposition of rhenium and platinum. The results of measurements are given and, in conclusion, some typical applications are illustrated with reference to large transmitting tubes.

Thermionic Grid Emission and its Effects

THE RAPID advances made by high-frequency techniques in the fields of television, v.h.f. broadcasting and generators for r.f. heating have created new tasks for the tube designers. The efforts to increase frequencies while reducing the dimensions and, where possible, improving the power output, are naturally accompanied by a rise in the specific load imposed on the elements of the tubes. The designer has to ensure adequate dissipation of the heat generated, if he is to avoid unwanted effects in the tube.

There are, however, tube electrodes—and this is particularly true of grids—whose temperature cannot simply be kept down by forced-air cooling or by radiation of the heat, for constructional reasons. There are even cases in which the grid in front of the hot anode, whose temperature may be in the region of 800–900 °C, are exposed to additional radiation. Before discussing the thermionic emission of the grid, it is pointed out that the following currents are flowing in the grid circuit:

Vacuum current	I_{gv}
Insulation current	I_{gl}
Thermionic grid emission	I_{gp}
Secondary emission	I_{gs}
Primary grid current	I_g
R.F. charging current	I_g'

the total grid current being denoted by i_g.

If the grid has a negative bias, the primary grid current and the secondary emission current are both equal to zero (Fig. 1). The positive direction

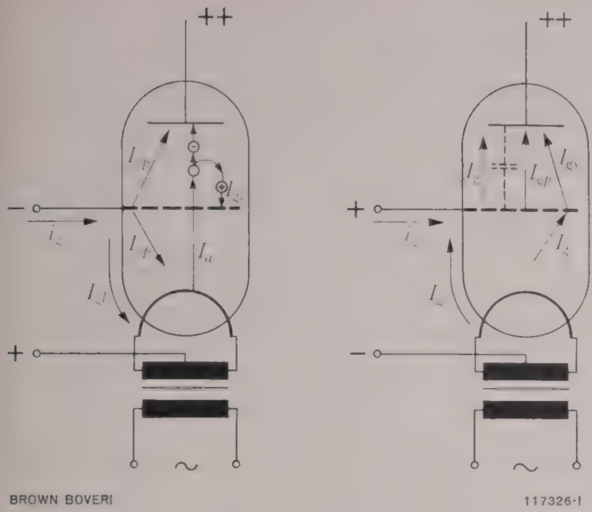

Fig. 1. – Components of the grid current

Left: tube with negative grid, but not blocking
Right: tube with positive grid

For notation see text.

is taken to be that of the electron movement in this case.

It should be pointed out that it is difficult to measure these currents singly with simple means; but the magnitude of the thermionic grid emission current can be determined quite accurately [1, 2, 3]. In conformity with the object of this article, namely to establish the requirements which a suitable grid material must fulfil and to check to what extent the new grids do in fact fulfil these conditions, only those portions of the total grid current will be considered which exert a direct influence on the selection of the grid material. These are, above all, the thermionic emission I_{gp}, the secondary emission I_{gs} and the r.f. charging currents.

A thermionic grid current flows when the conditions for grid emission are fulfilled. This current I_{gp}, whose value may amount to several mA under the most unfavourable circumstances in heavily loaded transmitting tubes, opposes the primary grid current I_g and thus reduces the current i_g flowing in the grid lead. In consequence, the negative bias of the tube is reduced by the voltage drop produced by I_{gp} in the grid resistance of several kΩ. The working point of the tube thus shifts in the direction of positive bias; the anode current starts to rise, the grid becomes still hotter, its thermionic emission grows rapidly, the grid voltage drops still further, and so on until the tube is destroyed.

Apart from the disturbance caused by I_{gp}, there is another resulting from the secondary emission of the grid. The secondary emission current also opposes the primary grid current, thus diminishing the flow of i_g. As a result the driving power is reduced, but although this may be desirable under certain conditions, it can lead to instability and changes in the characteristics of the tube. In general, the current I_{gs} ought to be as small as possible and, particularly in tubes of the same type, be kept constant.

The r.f. charging currents I_g' contribute an appreciable share towards the heating of the grid at high frequencies, unless the r.f. resistance is kept low by suitable design of the grid surface.

Conditions to be Fulfilled by the Grid Material

The density of the emission current j_s (in A/cm²) obeys Richardson's equation:

$$j_s = K\,T^2 \exp\left(\frac{e\,\varphi}{k\,T}\right) \qquad (1)$$

where T = Temperature [°K]
e = Electron charge [As]
φ = Work function [V]
k = Boltzmann's constant [Ws/°K]
K = a constant [A/cm² °K²]

The result of the above is that the grid, in addition to having a low operating temperature, should also have a high work function. The fulfilment of the latter condition, however, is rendered difficult by the fact that the grid is continuously subjected to vapour from the cathode, in particular with thorium if the tube has a thoriated cathode; the outcome of this is that its work function is considerably reduced.

A first condition is that the grid material must not evaporate at the high operating temperatures experienced during the whole life of the tube. This means that the rate of evaporation and, consequently, the vapour pressure of the material must be low. Table I shows at what temperatures the materials considered exhibit a pressure of 10^{-8} Torr.

TABLE I

Physical properties of different grid materials

Element	Melting point °C	Temperature at 10^{-8} Torr °C	Max. secondary emission factor (δ_{max})	Work function V	Spec. weight g/cm³	Total emissivity ε
Au	1063	780	1·4 at 1000 V	4·8	19·3	0·37 (100 °C)
Ti	1800	1060	0·9 at 250 V	3·9	4·5	0·43 (1000 °C)
Ta	3000	1970	1·25 at 600 V	4·1	16·6	0·21 (1500 °C)
Zr (ductile)	1857	1460	1·1 at 350 V	4·1	6·4	0·25 (1000 °C)
C	3652*	1700	0·75 at 350 V	4·6	1·8–2·5	0·81
Pt	1773	1280	1·8 at 700 V	5·3	21·4	0·15 (1000 °C)

* Sublimation

The secondary emission properties of the grid present a further problem for the tube designer. In contrast to the thermionic emission it is related neither to the temperature nor to the work function but, among other things, depends on the material used, its surface finish and on the potential of the electrode. In general, though, it may be said that I_{gs} is smaller, the rougher the surface and the lower the specific weight of the material. Some figures are given in Table I to illustrate this point.

Since the temperature of the grid in transmitting tubes may be of the order of 900–1200 °C (or even higher for heavily loaded grids), the high-temperature tensile strength of the material is a very important factor. Its ductility and coefficient of thermal expansion also play an important part.

The radiated power of the grid should be as high as possible. The relationship between the radiated power P and the temperature is given by the Stefan-Boltzmann law:

$$P = 5{\cdot}73 \times 10^{-12}\, A\, \varepsilon\, (T^4 - T_0^4) \qquad (2)$$

where A = the radiating area [cm²]
ε = the total emissivity
T = the temperature of the grid [°K]
T_0 = the ambient temperature [°K]

The factor ε is generally dependent on the temperature and only equal to 1 in the case of the ideal black body.

The poor heat radiation of polished metals can be improved by sand-blasting or graphite treatment, but these processes have certain drawbacks. In transmitting tubes with external anode the radiation towards the grid from the anode can be reduced by suitably treating the surface of the anode. In radiation-cooled tubes the temperature of the grid becomes very high because it is exposed to the radiation of the surrounding anode. In this case the emissivity of the grid is of minor significance.

The r.f. resistance has already been mentioned. If grids are coated with a separate material (see below), this must also exhibit excellent adhesion in addition to the above properties.

Examination of the Materials

The following remarks are based on tests carried out, some in the Company's own laboratories; publications from other sources are listed at the end of the article [1–5, 8–12]. Some metals, such as W and Mo, although they meet nearly all the conditions, must be disregarded because they possess the unwelcome property of being easily activated.

Pure Metals

Gold

Since gold is very expensive and insufficiently strong from the mechanical aspect, it is only employed as a coating on Mo, Mn–Ni, etc., primarily

in tubes with oxide-coated cathodes. Furthermore, it has a low melting point and its high rate of evaporation limits the operating temperature to 500–600 °C. Hence gold cannot possibly be considered for use in transmitting tubes [4].

Titanium

The drawbacks of titanium are its low mechanical strength, the low work function and the restricted range of the operating temperature. Titanium is effective in suppressing the thermionic emission of the grid in tubes with oxide-coated cathodes, but its temperature must not be more than 700–900 °C, otherwise the emission may result in poisoning of the cathode and deterioration of the insulation in the tube due to the condensation of titanium. The prospects of its being successfully employed in large transmitting tubes are therefore not very bright [5]. However, at low temperatures it is a very good getter.

Tantalum

This metal, which otherwise exhibits very favourable properties, has not proved satisfactory for grids. Its electron emission is one order of magnitude higher than that of tungsten (Fig. 2). Moreover, it is easily activated by the thorium evaporating from the cathode; this increases its emission by several orders of magnitude.

Zirconium

Its mechanical strength is very poor. Therefore it can only be used to coat a core of Mo, Ta or W, either by being sprayed on or by cataphoresis. Although a layer of this kind improves the emissivity of the grid, and though the secondary emission of zirconium is low, it does exhibit serious drawbacks [7]. With zirconized grids there is a risk of zirconium carbide forming on the surface, due to the action of C, CO or CO_2; this carbide has a very high electron emission, roughly equal to that of a W–Th cathode (Fig. 2). In transmitting tubes having a graphite anode, particles of the graphite can break loose from the anode and, landing on the grid, react to form ZrC.

Platinum

The use of platinum as a material for making grids was seriously considered among the group of

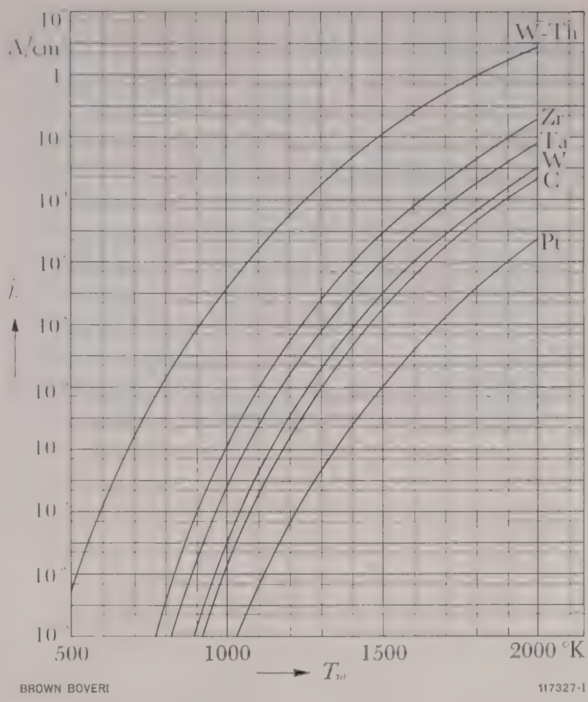

Fig. 2. – Thermionic emission j_e (A/cm^2) as a function of the true temperature T_w for thoriated tungsten, zirconium, tantalum, tungsten, carbon and platinum

pure metals regarded as likely possibilities. In favour of its use are the high work function and low thermionic emission (Fig. 2), as well as the invaluable property of not being activated by Th. The reason for this has not been discovered yet. Against its use are the high price of platinum, the poor emissivity, as well as the low mechanical strength and the high secondary emission. How it proved possible to overcome most of the drawbacks of platinum, while retaining its advantages, will be explained in detail later.

Non-Metallic Coating Materials

Another possible means of suppressing the emission of grids is to coat them with one of a number of non-metallic materials. The following materials have been used:

Carbon

Its high emissivity, equal to 80–90 % of that of the ideal black body, is very favourable indeed in that it often permits very high specific grid loads. The I_{gs} and I_{gp} properties are also advantageous. Its poor mechanical strength, however, prevents it being

Fig. 3. – Cross-section through a platinum-coated molybdenum wire

The thickness of the platinum layer varies between 10 and 37μ. Enlarged $\times$ 100.

used alone for the manufacture of grids. Carbon can only be used to coat such metals as W, Mo, Ta, Ti and Ni. Although this process is adopted for receiver tubes [8] the effect of the high temperature in transmitting tubes must be allowed for, as this can lead to the formation of carbide or to diffusion of the carbon in the basic metal and, apart from resulting in serious embrittlement of the grid material, also increases its thermionic emission by several orders of magnitude (see above). Its poor adhesion is often the cause of severe flashover in tubes.

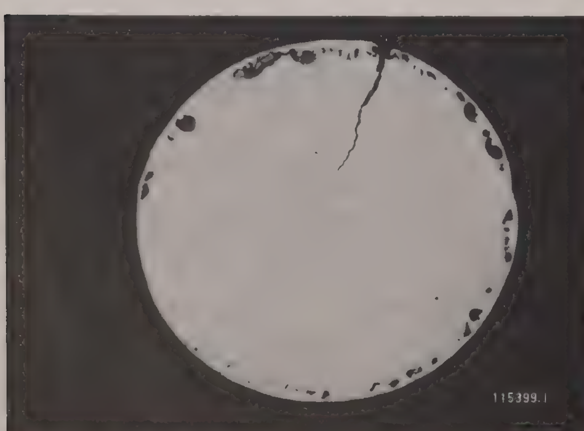

Fig. 4. – Faulty platinum-coated molybdenum wire with a cracked surface and oxide inclusions under the coating

Due to the penetration by the etching medium, the oxide inclusions appear unduly large in the photograph.

Enlargement $\times$ 110.

Oxides

Oxygen and its compounds suppress the thermionic emission owing to their electro-negative properties. From the patents WO_3, PtO, TiO_2, BeO, SiO_2, Al_2O_3, etc., are known. The poor r.f. conductivity, the low emissivity and the poor stability (cathode poisoning on decomposition) result in the view being taken that the use of these compounds in transmitting tubes does not achieve the desired end.

Carbides

So far ZrC, B_6C, TaC and MoC have been used. Apart from the good radiation in most cases and the high melting point of the carbides, there are serious reasons for not using them. These are the poor adhesive qualities, the high r.f. resistance, the brittleness of the grid and, above all, the rapidity with which they are activated by thorium. Thus, for instance, TaC is strongly activated by Th, likewise the subcarbide of tantalum αTa_2C which is produced when TaC is heated in vacuum [6]. With ZrC it is the electron emission, which is already too high, that is the disturbing factor. Subsequent treatment of the grid can partly overcome this drawback, but the gain achieved is very small compared with the expense.

Metallic Coatings

As already stated, there are metals which, though complying with the requirement of adequate suppression of the emission, suffer from other weaknesses, such as insufficient mechanical strength, tendency to diffuse, etc., and vice versa. In this case the best solution is to employ a combination of several materials. Most frequently use is made of the good properties of platinum by employing it as a coating. In addition to Pt other metals of group VIII of the periodic table have been suggested, but in the present case the remarks are confined to platinum.

Coatings with intermediate layer

If a coating of platinum is plated mechanically on a core of tungsten or molybdenum, a grid material with low thermionic emission is obtained and, at the same time since the thickness of the coating only amounts to about 0·02–0·03 mm on a Mo wire

0·4 mm in diameter, of quite high mechanical strength. Although this material has gained a great deal of ground in the last fifteen years as a material for the grids of transmitting tubes, it does suffer from some serious drawbacks. Firstly the radiation is poor (see Table I) because a smooth Pt surface is involved. The secondary emission current I_{gs} is also high. In addition, the thickness of the coating is not altogether uniform, giving a scatter band of 1:2 to 1:3 (Fig. 3). This brings in the risk of what are known as bimetal effects, because the coefficient of thermal expansion of Mo or W differs from that of Pt by about 100%; a further hazard are short circuits between the grid and the cathode in the warm state. Since the coating does not adhere very well to the core material, there is a risk of the grid being damaged during manufacture (Fig. 4). The outcome of this is that emission takes place from the part of the core metal not covered by Pt. This shortcoming was detected in wires supplied by numerous different manufacturers. The price of such a grid is also quite high, as a large transmitting tube has a grid surface of several hundred cm². The greatest hazard though is that the ability of platinum to prevent emission may be lost by diffusion between the Pt and the core metal at high temperatures [9, 10, 15].

Coatings with intermediate layer

There is a method by which the last-mentioned fault can be overcome, that is to apply a layer of Ta on the Mo core, to act as a barrier to diffusion of the Pt coating. Apart from the high price, the other drawbacks of smooth platinum wire are still evident. Wires with a carbide intermediate layer are also commercially obtainable, but they suffer from the disadvantages mentioned earlier.

The New Method

Description

During the development of a grid material with as low a thermionic emission as possible, the excellent properties of platinum-coated wire induced those concerned to adopt an approach which reduces the inherent drawbacks to a minimum.

The first task which had to be solved was to hinder the mutual diffusion occurring between the core metal and the Pt coating by incorporating an efficient barrier, which at the same time must be able to fulfil the conditions regarding melting point, adhesion, insensitivity to diffusion and ease of working. For this task an element in group VII of the periodic table was selected, namely rhenium, which has a melting point of 3167 ± 60 °C. Among other things, it is notable for its ability to be deposited electrolytically in a thin film only a few μ thick on the core material. Its much better adhesion compared with a carbide coating is gained by sintering in hydrogen or in vacuum at a high temperature. The sintered rhenium layer then forms a cohesive envelope round the core wire, thus preventing the latter from making contact at any point with the platinum coating applied later. This was the first step towards treating the continuously produced grid material.

Next follows the application of the platinum coating to the prepared wire. In order to keep the consumption of this very expensive metal as low as possible and to be able to vary the thickness of the coating at will, it was decided to adopt the electrolytic method of deposition from a platinum salt. This metal is easily deposited on the rhenium undercoating. The final operation is sintering in hydrogen or in a vacuum at an elevated temperature [13].

The above description of the new process adopted by Brown Boveri does not claim to be complete, a number of details having been omitted for the sake

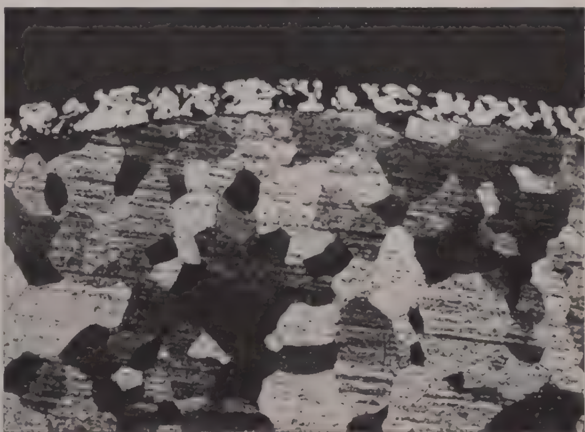

Fig. 5. – Cross-section through a molybdenum wire coated with rhenium and platinum

Enlargement ×200.

of simplicity. A few more important features of the method may, however, be mentioned briefly. Since the electrolytic application of the two coating metals ensures a thin coating of uniform thickness (Fig. 5), the bimetal effect is ruled out from the start. It is also possible to choose almost any desired surface finish of the Pt coating by varying the current during electrolysis and the composition of the electrolyte. The emissivity[1] benefits from this, with the result that a grid coated with Re–Pt can carry from 2·5 to 3·0 times as much specific load at a given temperature as a wire of bare platinum. In other words, the temperature of the Re–Pt wire at a given specific load can be 25–30 % lower than that of a grid made of bare platinum wire (see also equation (2) on page 396).

With heavily loaded grids (over 15 W/cm²) there is a risk of the electrode temperature rising to the melting point of the platinum coating, leading to the formation of alloys by the Re and Pt. This risk is greatly diminished by applying a layer of carbon between the two metals because Re does not form carbide with C in the temperature range involved. In contrast to the former method in which the object of the carbon was to form a carbide layer, in the Brown Boveri method the carbon is intended to retain its identity and not form an additional barrier as carbide [14].

By roughening the surface of the finished wire it is possible to reduce the secondary emission by about 50 %. Since the surface finish of the wire can be prescribed in the coating process and is easily controlled, it ensures uniform production and, for the grids, equal secondary emission currents.

Finally, since the coating has to be only a few μ thick and is consequently negligible compared with the thickness of the core wire (200–500 μ), the core of Ta, W or Mo retains its mechanical strength,

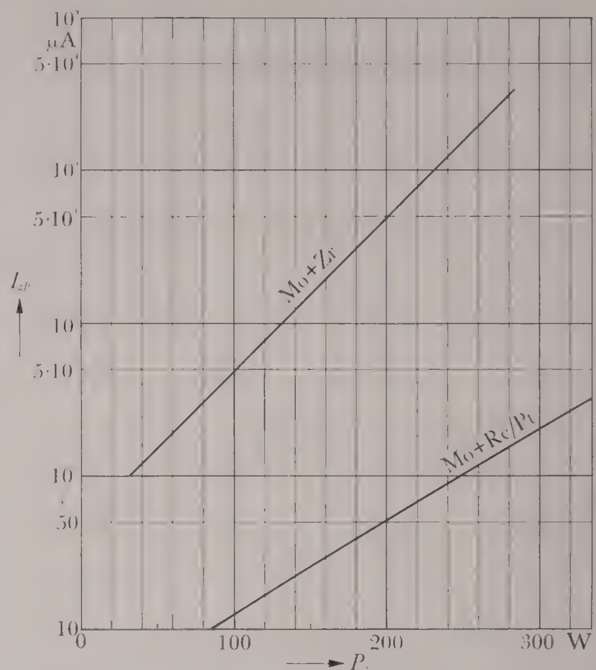

Fig. 6. – Thermionic grid emission I_{gp}

plotted against the grid load P_g for molybdenum grids plated with zirconium (old method) and with rhenium and platinum (new method).

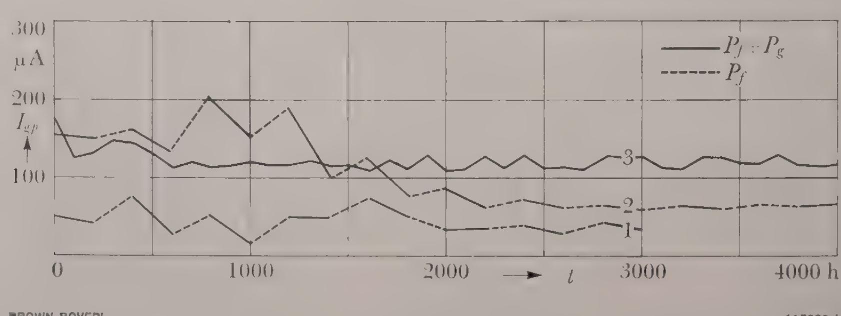

Fig. 7. – Change in grid emission I_{gp} during the tube life t for grids with rhenium-platinum coating

Curve 1: Industrial tube type FTL 8–1.
Dotted: with cathode heating only.
Full: with heated cathode and loaded grid.

Curve 2: Tube type BTW 15–1, as for 1.

P_f = Filament heating power
P_g = Grid loading

Curve 3: Tube BTW 15–1: Current I_{gp} measured every 100 h during operation in the output stage of a short-wave transmitter.

[1] $\varepsilon = 0{\cdot}4$–$0{\cdot}5$ compared with 0·15 of bare platinum, see Table I.

ductility and non-deformability. Furthermore, it is impossible for the wire to become brittle because the sintering process eliminates all possibility of diffusion between the core metal and the coating, provided the right temperature is employed. It is quite an easy matter to produce grids of any desired form from the treated wire.

The above method does not, of course, rule out the possibility of coating complete grids.

Results of Measurements

It would exceed the scope of this article if all measurements were to be discussed; for this reason only a few of the more important conclusions are picked out. Fig. 6 shows the relationship between the thermionic grid emission and the load on the grid. This diagram is convincing proof that, at a load of 300 W, a grid emission of about 200 μA in a grid resistance of 1·7 kΩ only causes a voltage drop of 0·34 V. Compared with the grid bias of 600 V this is, of course, negligibly small (tube type FTL 8–1 at full load). How constant the emission of the Re–Pt

Fig. 8. – Cross-section through the grid wire coated with Re–Pt, taken from the tube type BTW 15–1 (Fig. 7, curve 3) after 4000 h service

Enlargement ×500.

remains in service—and this is far more important than the absolute value—is shown by Fig. 7. Curve 1 shows the thermionic grid emission of a tube type FTL 8–1 used in an industrial r.f. generator. These measurements were carried out in such a manner

Fig. 9. – Brown Boveri tubes for industrial r.f. generators

From left to right: types FTL 12–1, FTL 8–1, FTL 3–2, FTL 3–1, T 1000–1, T 350–1.

Fig. 10. – Brown Boveri vapour-cooled transmitting tubes (CFTH evaporator)

From left to right: types BTS 6–1, BTS 15–1, BTS 25–1, BTS 50–1.

TABLE II

Operational data of some Brown Boveri tubes employed in industrial r.f. generators and transmitters

Type	Filament voltage V	Filament current A	Anode voltage kV	Output power in class C unmod. kW	Admissible anode dissipation kW	Cooling system	Frequency Mc/s
Tubes for industrial r.f. generators							
T 350–1	5·0	15	4	1·1	0·35	radiation	75
T 1000–1	8·5	26	5	3·1	1·0	radiation	60
FT 3–1	12·0	26	6	6·3	3·5	air	60
FT 3–2	12·0	26	6	6·3	5·0	air (FTL 3–2) water (FTW 3–1)	60
FT 8–1	8·0	80	10	19·2	8·0 15·0 15·0	air (FTL 8–1) water (FTW 8–1) vapour (FTS 8–1)	60
FT 12–1	8·0	105	12	32·4	12·0 20·0 20·0	air (FTL 12–1) water (FTW 12–1) vapour (FTS 12–1)	30
Vapour-cooled transmitting tubes							
BTS 6–1	6·3	120	11	21·3	12	vapour	100
BTS 15–1	7·5	150	12	42·5	27	vapour	100
BTS 25–1	10·0	320	15	72·5	40	vapour	50
BTS 50–1	20·0	200	15	145	75	vapour	35

that the grid was loaded for a period of 200 h followed by 200 h at no-load with only the heating current switched on, giving it a chance to become activated in this period. Curve 2 shows the corresponding result for the transmitting tube type BTW 15–1. Curve 3 shows the result of an endurance test on the latter type of tube in the output stage of a short-wave radio transmitter.

On completion of these measurements the tubes were opened and the grid wire examined under the microscope. In Fig. 8 the state of the grid wire of the tube (curve 3) can be seen from the cross-section magnified 500 times, after about 4000 h service. The coating is still intact and has retained its rough surface conducive to good heat radiation. Free particles resulting from poor adhesion were not found in the tube.

Applications

The grid material produced by this new method was first introduced into tubes having heavily loaded grids. These are mainly the tubes used in industrial r.f. generators, whose grids are subjected to very severe stresses, particularly at no-load, and

are the tubes most likely to suffer if exposed to excessive grid emission (Fig. 9). No less important is the provision of a robust grid capable of carrying overloads for large vapour-cooled transmitting tubes, in order to benefit from the vapour-cooled tube's ability to withstand anode overloads during fluctuation of the load or modulation peaks (Fig. 10).

Table II summarizes the most important operational data of a selection of tubes in both groups. Two more radiation-cooled types with anode dissipations of 600 and 2000 W are being developed to augment the range of tubes for industrial r.f. generators.

(KME) M. Deák

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PUSH-BUTTON OPERATED MOTOR PROTECTING SWITCHES RATED 25 A

621.316.573

This article deals with the design and electrical properties of the new Brown Boveri motor protecting switch for a current rating of 25 A, based on the same lines as the popular type P 10 switch. Special attention is drawn to the ease with which this unit can be installed and the simple wiring facilities.

THE MANUALLY OPERATED motor protecting switch type P 10 which was first marketed about ten years ago, for actuation by push-buttons, and having a current rating of 10 A, has proved very successful indeed in the industrialized countries and in under-developed territories, where it has had to operate under a wide variety of climatic and service conditions. Consequently, the design of the new manually operated switch for 25 A, fitted with push-buttons, and designated type P 25, described in the present article, is based on the same lines. It is also compact, occupying a minimum of space, has a high breaking capacity, affords universal connection facilities and is easy to install. Its strong sheet-metal casing offers admirable protection in dusty and damp areas and is attractive in appearance (Fig. 1).

In the 25-A switch it was possible to incorporate some internal elements which had to be dispensed with in the 10-A unit, for instance auxiliary contacts, tripping solenoids for operation by make or break contacts, time-lag mechanism for retarded undervoltage trip; facilities are also provided for interlocking with other elements, but this will be discussed later.

Fig. 1. – Motor protecting switch type P 25 rated 25 A

It is operated by large, protected, mechanically functioning push-buttons.

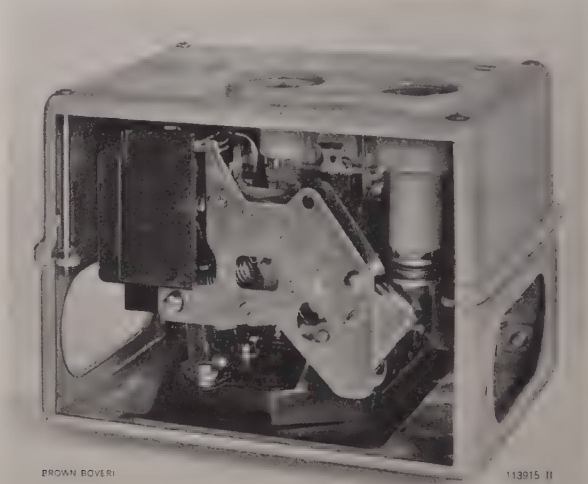


Fig. 2. – Motor protecting switch type P 25

In this cut-away view through one side of the casing the robust operating mechanism and push-buttons can be seen.

TABLE I

Rated current	with release block		25 A
	without release block[1]		30 A
Rated voltage			500 V
Test voltage			3000 V
Peak making current			800 A
Max. admissible breaking current A.C.	non-inductive load at 500 V		800 A
	inductive load at 500 V, p.f. 0·35		250 A
D.C.	non-inductive	110 V	300 A
		220 V	135 A
		440 V	10 A
	inductive ($L/R = 15$ ms)	110 V	200 A
		220 A	50 A
		440 V	5 A
Break time			10–14 ms
Number of switching operations which the mechanism can withstand			250000

[1] As normal triple-pole switch type PG30

Like the switch type P 10 for 10 A, the new 25-A unit is operated by large, protected, mechanically functioning push-buttons (Fig. 2). The switching element has non-chattering contacts of heavy silver with double interruption to achieve a high breaking capacity (Fig. 3). The operating mechanism is designed to close the contacts rapidly and completely; inching action, which would lead to severe contact erosion, is quite impossible. Arc-chutes enclose the quenching space on all sides, so that even when a heavy load is interrupted, the arc cannot possibly emerge and cause flashover. Details of the electrical properties and life are listed in Table I above.

The three directly heated thermal releases are combined to form an easily interchangeable block (Fig. 3). At the top of this block is a scale for setting the releases jointly to the motor current involved. Altogether ten setting ranges are available, between 0·23 and 25 A, each overlapping the next.

The thermal releases can withstand 50 to 100 times the set value within the corresponding tripping time and, when combined with series fuses, as per Table II, are capable of withstanding short circuits. As may be seen from the curves in Fig. 4, the tripping time with very heavy short-circuit currents is only a fraction of a second, so that the releases can also perform the duties of high-speed releases, thus obviating the need for special magnetic releases. Owing to the incorporation of temperature compensation their action is unaffected by changes in the ambient temperature.

In its basic design the switch has an earthing terminal on the outside and, on the inside, provision for connecting a protective wire with a copper cross-section of 2×16 mm² (Fig. 5). For use in networks having an insulated neutral the switch can be equipped with an insulated neutral terminal. Two auxiliary (make or break) contacts can also be provided, and an undervoltage or series trip coil. Instead of an auxiliary contact it is also possible to

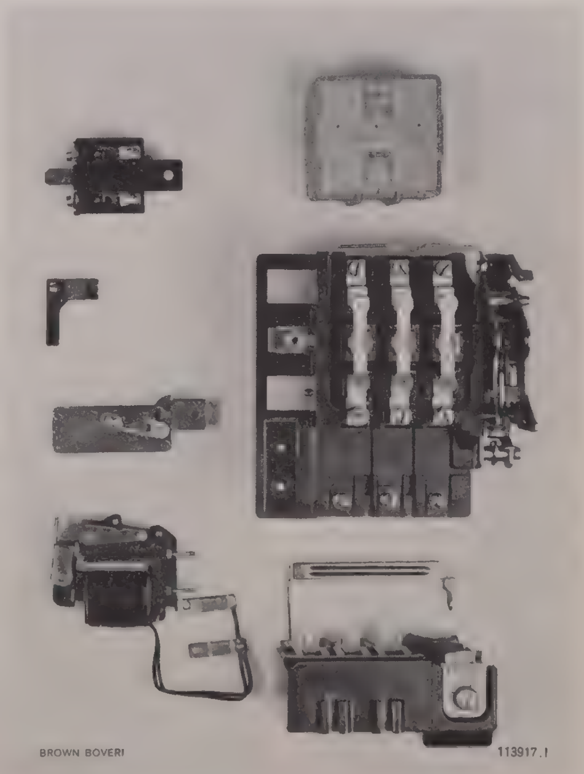


Fig. 3. – The active parts of the type P 25 switch

Each component can be supplied separately.

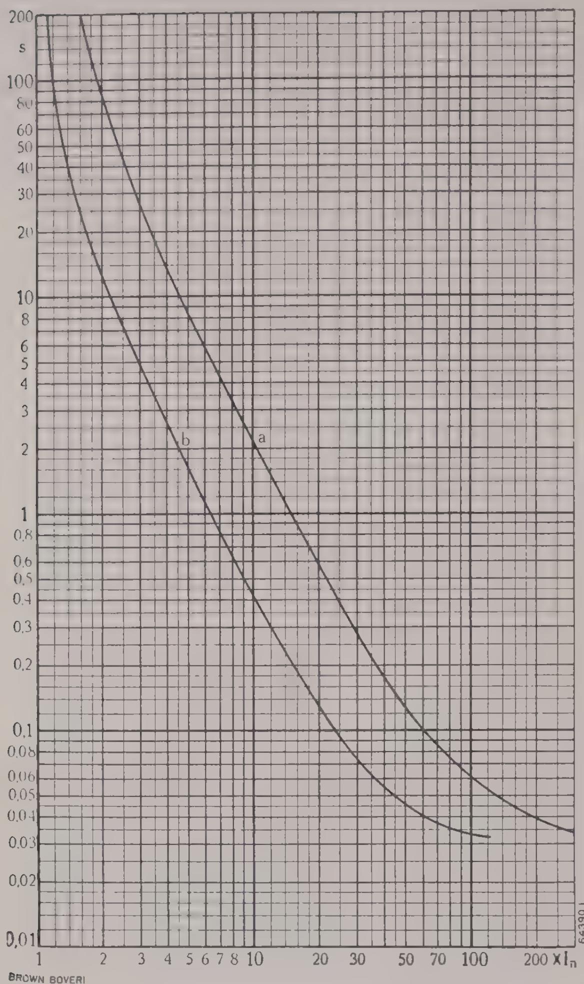


Fig. 4. – Tripping characteristics of the thermal releases

Abscissae: Multiple of the release setting I_n

Ordinates: Tripping time in s

a: from cold

b: when warm from running

TABLE II

Maximum fuse ratings required on the various settings of the thermal releases

Setting range of releases (110–500 V a.c.)	Series fuse rating	
	instantaneous	retarded
0·23 – 1·0 A	40 A	25 A
0·9 – 1·6 A	25 A	20 A
1·5 – 2·5 A	25 A	25 A
2·3 – 6·5 A	40 A	25 A
6 –10 A	60 A	50 A
9 –16 A	80 A	50 A
15 –25 A	80 A	60 A

incorporate a timing mechanism for retarded undervoltage trip (Fig. 6). In models with unretarded undervoltage trip and one auxiliary break contact the switch can easily be interlocked with another

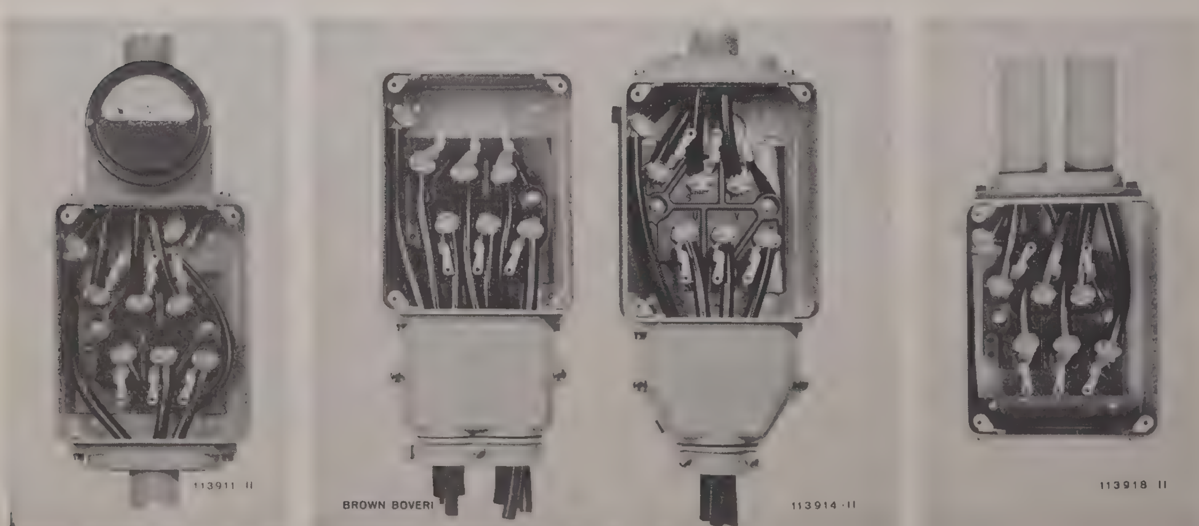


Fig. 5. – Alternative ways of installing and wiring the type P 25 switch

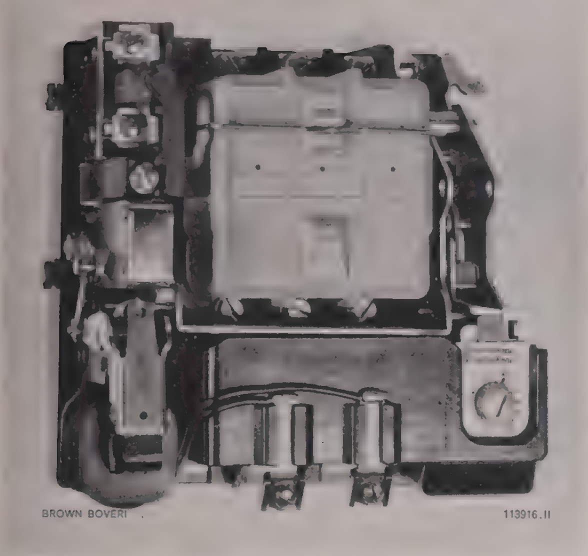


Fig. 6. – The active part of the motor protecting switch type P 25

Switch element with arc-chute, operating mechanism, release block and the optional parts: tripping solenoid, timing mechanism, auxiliary contact. Together a compact assembly.

Fig. 8. – The motor protecting switch type P 25 for flush mounting in machines and switchboards

The front cover-plate can be removed without having to dismantle any other parts, and the active part is easily accessible from the front.

element in such a manner that closure is only possible when the latter element, which may, for instance, be the rotor starter of a slip-ring motor or the zero locking contact of a shunt commutator motor, is in the zero position. If the interlocking circuit is open, the contacts do not move at all when the I button is pressed, thereby reliably avoiding even brief starting by the motor and the risk of harming the operating staff.

The following models are available:

1. Switch with a tightly closing sheet-metal casing (Fig. 7) for installation in dusty and damp areas.

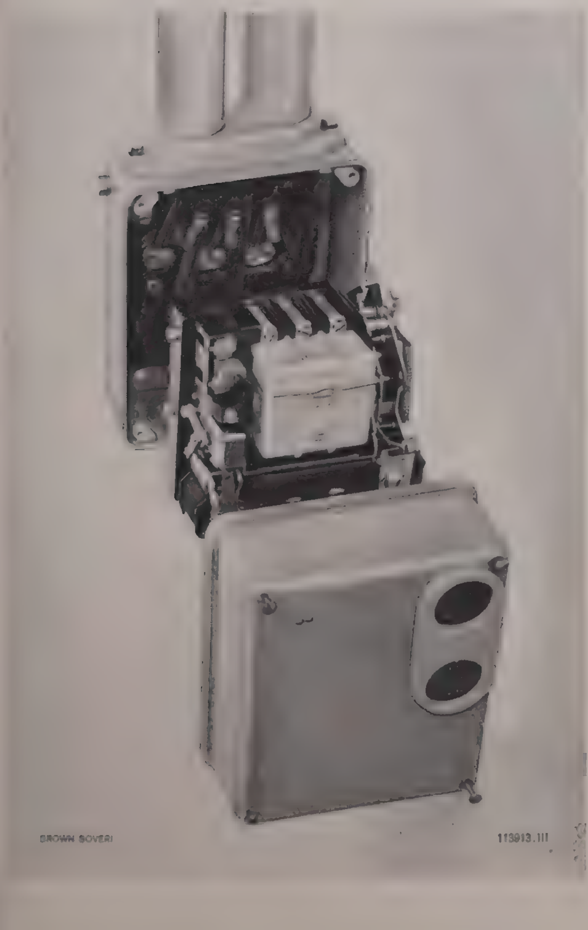


Fig. 7. – Switch type P 25 with sheet-metal casing

Suitable for dusty and damp areas, with standardized openings for cable entry. A large selection of conduit glands and cable sealing boxes is also available.

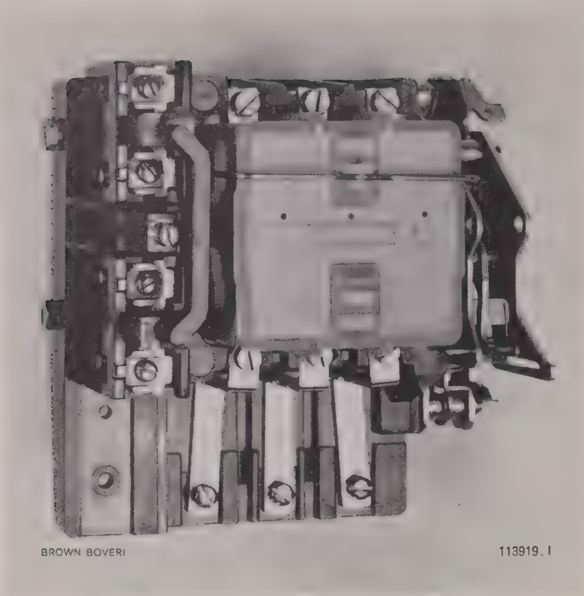


Fig. 9. – Enclosed-type switch type PG 30 rated 30 A

Showing the active part of the switch with three shorting links and two extra auxiliary switches.

It can be supplied with ammeter, conduit glands for different threads or with cable sealing boxes, to suit all conditions likely to be encountered on site. The leads can also be brought in through knock-outs in the back of the casing. Suitable adapting parts are also available, allowing the switch to be joined to other units from the Brown Boveri industrial switchgear range.

2. Switch with front cover-plate (Fig. 8) for flush mounting in machines and switchboards.

To simplify installation of the wiring, a separate terminal block is fitted to the back-plate of the casing (Fig. 5), to which the leads can be connected before the rest of the switch is inserted in the box. This provides plenty of space and unobstructed access to the terminals when looping in and connecting up the wiring. Afterwards the active part of the switch is simply inserted and fixed in position with six screws, which simultaneously complete the electrical connection to the switch contacts.

The unit can also be supplied as an enclosed switch, in which the three thermal releases are replaced by shorting links. In this case the current rating can be increased to 30 A because the heating effect of the thermal releases is no longer present. A block with three shorting links can also be supplied for cases in which thermal releases are not required, but a tripping magnet is.

The design of the new motor protecting switch for 25 A was prepared with the necessary care and precision, and incorporates the many years' experience accumulated by Brown Boveri in this field. It complies with the relevant standards, in particular Publication No. 138 of the Swiss Electrotechnical Association (SEV). All stipulations of this standard are amply fulfilled and the prescribed mechanical and electrical tests were passed with ease.

(KME) W. KÄGI

BRIEF BUT INTERESTING

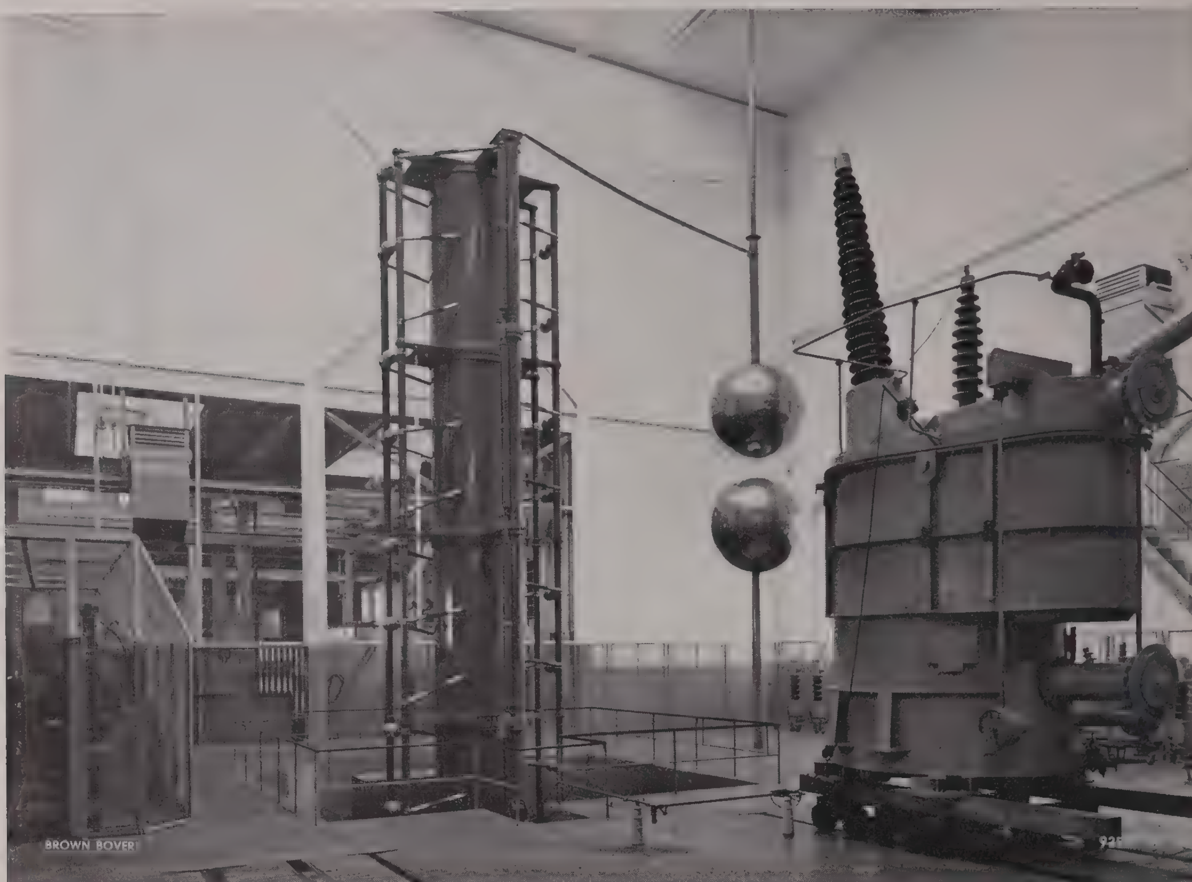
250 Large Transformers Impulse Tested

621.314.21:621.317.333.8

RECENTLY the 250th large power transformer to be subjected to impulse tests left the Baden factory. It is fitting that attention should be drawn to this "jubilee" and, in a brief review of the long road covered, to pick out some of the milestones passed on the way.

About forty years ago, in close collaboration with Brown Boveri, the Swiss Electrotechnical Association (SEV) adopted what was then called the "Sprungwellenprobe", simulating transient overvoltages, as a means of testing transformers. This test involved the generation of a series of sparks between the high-voltage terminal of the unit being tested and earth, lasting a few seconds at 1·3 times the rated voltage. On account of the method's aptitude for locating serious faults in the coil, it is still in use today, now being known as the impulse test. However, it was not long before the conviction began to gain a hold, that in this form it did not adequately fulfil the conditions likely to be encountered in service, the suggestion being made that atmospheric overvoltages should be simulated by a single surge with a considerably higher peak value. By and large it was possible to produce such voltages with a generally known form at the beginning of the 1930s, but the main difficulty was to recognize damage in the insulation at such voltages, lasting barely a millionth of a second and, perhaps, causing only a pin-hole puncture in the insulation of one turn, for example. An important advance was the introduction of the method of checking the effect of the impulse, designed and developed in the Brown Boveri laboratories, employing the oil-pressure detector. In the same or slightly modified form this method is also employed by many other firms today. When, towards the end of the second world war, the Hagenguth method of checking the impulses was brought out, in which not only the impulse voltage is measured, but also the current to earth, using a fast-sweep oscilloscope, investigations into the suitability of this new method were immediately carried out by the Company. The results proved that every change in impedance due to the slightest defect in the insulation does indeed provide an unmistakable indication, due to the momentary capacitive and subsequent inductive deviation in the measured values, and often allows a statement to be made regarding the location of the fault. Instead of measuring the neutral current, good results have also been obtained, for instance, by determining the current in the iron circuit and the tank, the outgoing current from the secondary winding, or even a suitable secondary voltage.

While work was still in progress on the development of a satisfactory method for impulse testing of transformers, customers were already beginning to stipulate this special insulation test. In 1948 a start was made on these tests, at first more in the form of private trials on isolated units to give the laboratory staff practice or to test out certain critical insulation arrangements. Even in the ensuing years the number of tests was quite small. Not until 1953 did the number of single or three-phase transformers sent in for impulse testing rise sharply to over 20, the annual average remaining slightly above this figure till the present. In order to fulfil the associated requirements, a special laboratory was built with its own high-capacity impulse generator (3·6 MV, 100 kWs) and all the necessary measuring and supervisory equipment (1954). With it the prescribed wave-form can be maintained, even in unfavourable cases; instead of the provisional arrangement, the organization of the testing facilities was largely rationalized and freed from disturbances. Today the installation (see illustration overleaf) is only used in rare cases for development work and far more for acceptance tests. In addition to the full-wave impulses and those chopped in the tail, there came, especially for transformers being supplied to America, tests with impulses where chopping is effected during the rise of the wave-front. Special attention was paid to the exacting test technique involved.



Impulse testing laboratory for large transformers

From left to right: Control room, impulse generator 3·6 MV/100 kWs, spark gap for measuring, test object.

There were, of course, frequent setbacks, but valuable new knowledge was also gained. In a—necessarily very rough—classification of the defects occurring, at the start the majority proved to be in the main insulation (due to the use of unsuitable supporting sleeves or inadequate insulation of the leads and protective rings); next in order came coil defects due to the conductor insulation not being properly adapted to the longitudinal stresses. As knowledge of the most severely stressed points, or of the true stresses improved, as a result of exhaustive calculations and experimental measurements on models, furthermore, with exact knowledge of the true dielectric strength between two paper-insulated conductors, having carried out numerous investigations with wire specimens and by specially designing the initial coils on the windings of e.h.v. transformers, faults of the above kind became increasingly rare. In their place there appeared faults at points where prediction was very difficult, such as parts of the secondary windings, interconnecting leads, tappings and switches. Compared with the total number of transformers subjected to impulse tests, however, the number of defects represents only a very small fraction. Moreover, it must not be overlooked that, in recent years, not only have the voltages and powers of large transformers grown at an unprecedented rate, but also that the stipulation of facilities for varying the ratio over a wide range, frequently on-load, and the growing importance attached to the auto connection, have rendered them much more complicated, yet in nearly every case the problems of impulse strength were of prime interest.

In passing, it may be mentioned that, in addition to these problems in the construction of large transformers, other questions were also dealt with, such as the internal and external impulse strength of high-voltage instrument transformers and distribution transformers. Apart from adapting the insulation more closely to the stresses, the technique of impulse testing was also greatly improved for these units. A number of publications have kept the technical world informed of the progress achieved in all these spheres.

But though this review also mentions the occasional disappointments and temporary worries, this only helps to underline all the more forcibly how valuable this new method of testing was as a means of eliminating weaknesses, even though it appeared at times that the normal requirements of everyday service in power networks were being unduly exceeded. Cases are indeed known of transformers which would certainly have given perfectly reliable service although they failed to pass the test; either the steep rise of the laboratory impulse would never have been attained in the network (e.g. on account of the high initial capacitance of the test object or the station, or owing to its being connected by cable), possibly the configuration of the network would have made such a high voltage quite impossible. An obvious proof of the blessings of this test, which was incorporated as a type test[1] in the SEV Rules in 1956 is that, whereas formerly thunderstorms often caused defects in transformers, such phenomena, and above all, breakdowns due to switching overvoltages, have now become a distinct rarity. Of course the improvement of overvoltage protection systems and, generally speaking, the much smoother co-ordination of the high-voltage equipment in networks has also contributed to this improvement in the overall reliability. But it will not be possible to determine the effectiveness of the individual measures separately.

Hence, although the special insulation test with impulse voltages sometimes gave us cause to worry, the difficulties encountered were all overcome by incessant detailed work, and everything possible was done to improve the impulse strength of Brown Boveri transformers and to guarantee their performance in service. This is ample reward for the effort put in and an encouragement for future work.

(KME) B. GÄNGER

[1] SEV Publication No. 0189: Regeln für Transformatoren.

The Thousandth "Thyralux" Unit Leaves the Factory

621.316.722.076.7

READERS will doubtless know that the "Thyralux" unit is an electronic dimmer, specially designed for varying the light output of fluorescent lamps. Owing to the drooping characteristic of tubes of this kind, their output cannot be varied with conventional means. Continuous control, free from flickering and abrupt changes in the illumination, is best obtained with electronic means. In practice the "Thyralux" has proved to be ideal for this task and, owing to its apt design, with a range of suitably graded outputs, and its easy control, has attracted considerable attention from illuminating engineers. The Thyralux contains two thyratrons fed from the 220-V a.c. mains and in series with the load. By connecting the thyratrons in anti-parallel, the a.c. supply, an essential factor for gaseous discharge tubes, is assured. The power consumed by the load circuit, and thus the brightness of the lamps, is controlled by varying the ratio of the conducting period to the inverse period during each half-wave of the alternating current, by the simple yet reliable system of grid control (phase bridge). On pressing a push-button, which may be located any distance from the dimmer, a built-in servo-motor can gradually increase the brightness from zero to full (or conversely) over a period of 10 to 30 s, the change being perfectly smooth and free from flicker. Facilities are also provided for stopping at a preset value.

The thousandth Thyralux passes its final tests

When loaded, i.e. when passing current, the thyratrons exhibit the characteristic iridescent light visible in the picture, caused by collision between the gas atoms and electrons.

Since the maximum controllable output amounts to 6·3 kVA (28·6 A at 220 V), it is possible to connect up to 70 fluorescent 40-W tubes to a Thyralux unit, using a special built-in shorting contactor. But it can also be used with high-voltage cold-cathode tubes or up to 110 filament lamps rated 60 W. Several units can be combined and controlled from a single point when heavier loads are involved.

The life of the thyratrons in this unit is almost unlimited; firstly because the Brown Boveri thyratrons type TQ 2/6 with mixed filling, manufactured by the well-known "pellet" method, attain a very long life under any circumstances, and secondly because the tubes are short-circuited as soon as the lighting reaches full strength, and are therefore not required to emit at full illumination.

This robust electronic unit can be installed quickly anywhere quite cheaply. In the eight years since it was first marketed, a total of one thousand units has been taken into service, abroad as well as in Switzerland, for lighting cinemas, theatres, lecture and concert halls, restaurants, hospitals, aviaries, airport runways, and so on. The 1000th unit left the factory at the end of January 1961. One thousand installations with 2000 "pellet-filled" thyratrons are eloquent proof of the advantages of electronic control in general, and for the Thyralux and Brown Boveri thermionic tubes in particular.

(KME) R. HÜBNER

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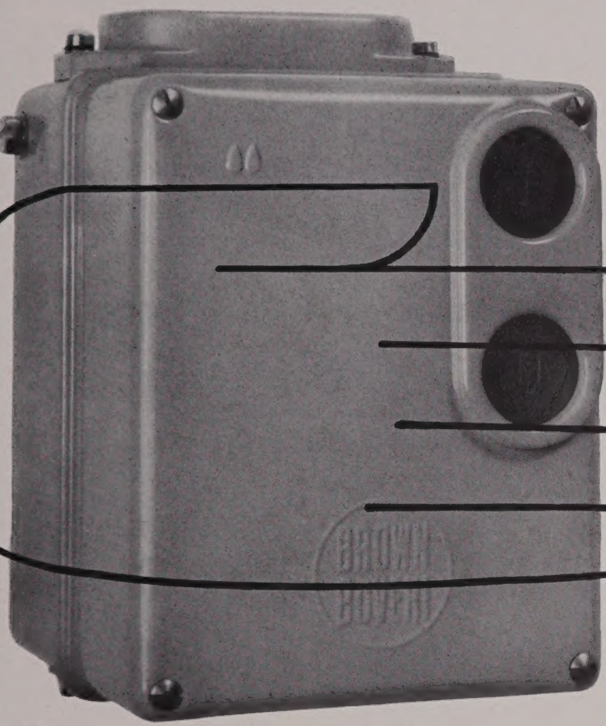

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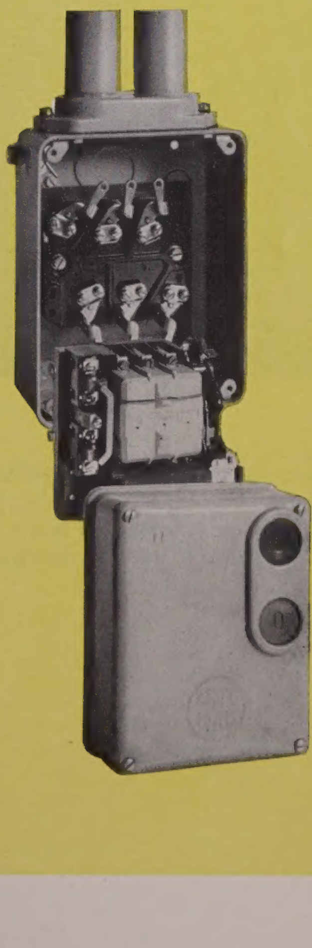
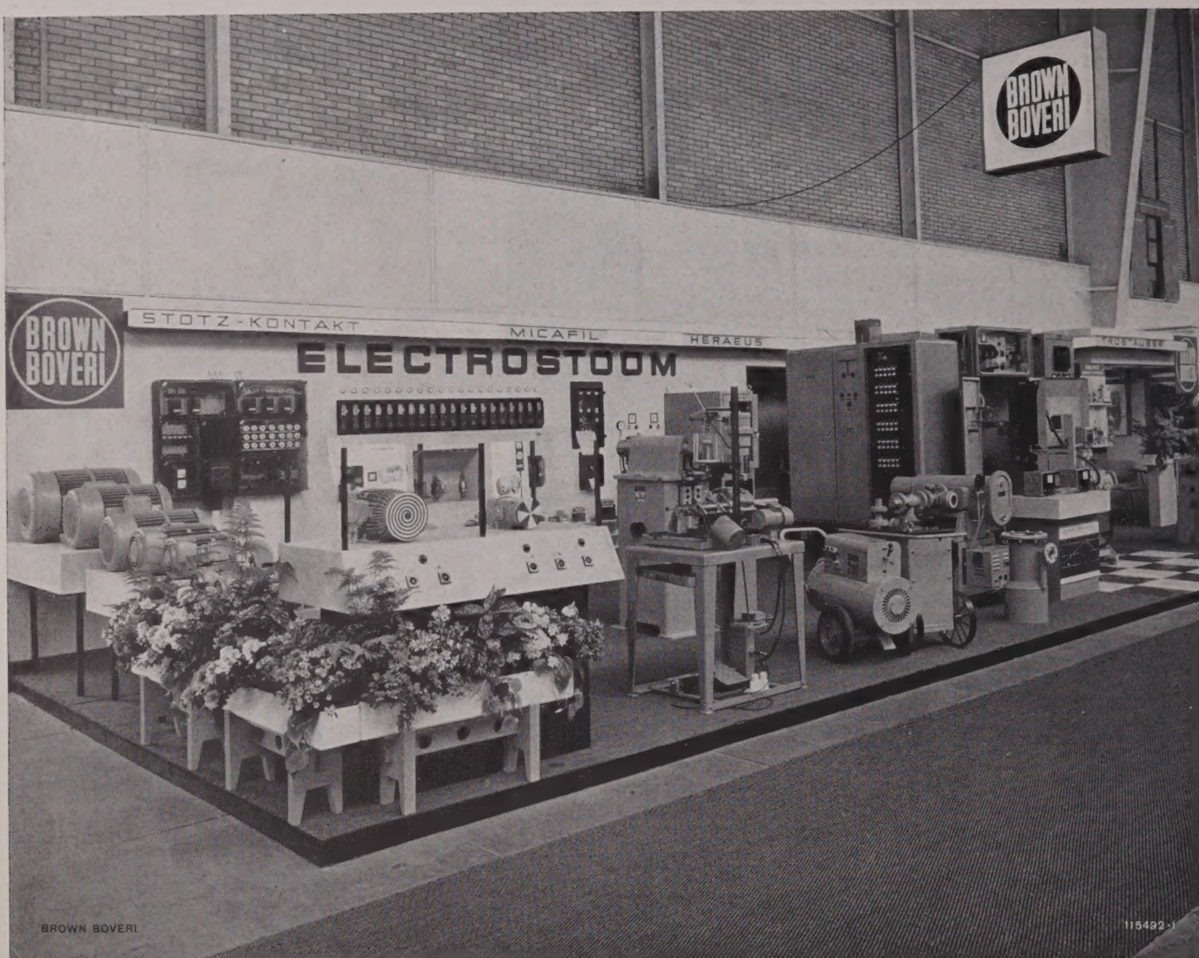


Brown Boveri at Spring Fairs 1961



International Spring Fair held in Utrecht (Holland) from March 13th to 22nd, 1961

Showing the joint stand of Brown Boveri, Baden, and Electrostoom, Rotterdam. On the left, the new range of TEFC motors; further to the right, converter and transformer for electric welding; behind the latter is a silicon rectifier cabinet.

Swiss Industries Fair, Basle, from April 15th to 25th, 1961

View of the main stand devoted to power engineering, electronics and high frequency. In the foreground is one pole of the new airblast circuit-breaker type DKF for 220 kV, with a breaking capacity of 16000 MVA. Left of it a model of the gas-turbine power station for Afam in Nigeria with two 10·3-MW turbosets.

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